OPERATIONS AND MAINTENANCE MANUAL

MODIFIED LOGAN FREEZE/THAW CABINET

Prepared by Michael Sock

RHODE ISLAND DEPARTMENT OF TRANSPORTATION
RESEARCH AND TECHNOLOGY

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* Moved again, in August 2004. On wheels this time, so I was able to maneuver it myself. Wish we'd thought of that in 1993.

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INTRODUCTION

The second RIDOT freeze/thaw machine owned by RIDOT is a modified Logan Freeze/Thaw Cabinet, which had been designed to conform to ASTM C666 Method A (the modifications to the system do not affect its conformance); Appendix F contains a graph showing the temperature recorded through typical cycles to confirm that the machine stays within the requirements of C666 (a variation of no more than 3.3°C throughout the specimen chamber). The machine was purchased in 1993 and was provided with no temperature control or data recording system. At our request, the manufacturer installed a relay to allow the machine to be switched from the cooling phase to the heating phase by computer (it was later decided to add relays to control the main power, heating system and circulation fan). An Advantech PCL-711b analog/digital input/output ISA bus PC expansion board is installed in a standard x86/DOS machine. Once the program is started and the cycle length is entered, operation of the machine is automatic. The refrigeration and heating systems remain unmodified. A more detailed description of the modifications made is given in Appendix C.

THEORY OF OPERATION

The equipment is intended to simulate the freezing and thawing environment that concrete would be exposed to in certain climates. When concrete, in normal exposure to the elements, absorbs water and then is subjected to temperatures that alternate above and below freezing for extended periods of time, the expansion of the water as it turns to ice can cause internal stresses in the concrete, causing microcracking. Ultimately, this can result in the failure of the concrete as the microcracks network and form larger cracks. When the concrete in question is structural, the resulting damage can significantly reduce the life of the structure.

Modern concrete mixes routinely incorporate an admixture which causes the concrete to entrain air. The void structure that is formed when the concrete cures acts to relieve stress by allowing cavities for the moisture to expand into when it freezes (note: these cavities are normally microscopic). The higher the air content (entrainment), the better the resistance to freeze/thaw deterioration. The tradeoff comes in the concrete strength; as the air content increases, the strength of the cured concrete decreases. Determining the freeze/thaw durability of a given mix at a given air content therefore becomes very important to allow a satisfactory balance. Other factors can also affect freeze/thaw performance, especially coatings (type, thickness, application) and additives.

The machine subjects concrete specimens to rapid freeze/thaw cycling while they are maintained in a saturated condition. The cycling is intended to simulate the normal conditions of a moderate to severe cold weather climate. The specimens are removed from the machine in a thawed condition once every thirty-six cycles or less (per ASTM C666) for testing. This allows the deterioration of the specimens to be charted.

ASTM C666 (reproduced in Appendix A) is considered to be a particularly harsh test by many concrete product manufacturers and some test organizations. That the specimens are kept in a saturated condition, with very little clearance for the water around the sides (causing high surface stresses as the water freezes), with short cycling times (possibly generating increased stresses due to thermal shock) and relatively small specimens (whereas field concrete tends to be fairly massive and less likely to freeze throughout), this opinion seems somewhat justified. Considering the New England environment, however, (especially near the coast), the severe test conditions are necessary to insure confidence in the survivability of the concrete being tested. Note that the physical layout of the machine places the specimens long dimension horizontally. Further, the nature of freezing water causes the top of the specimen to ice over first and also to thaw last (each specimen has one heating element on either side, placed near the bottom of the specimen). This means that part of the specimen near the top is being frozen very rapidly, in effect "shock" freezing the concrete. This tends to accelerate the deterioration of inferior (low quality aggregate, low air entrainment, etc.) concrete in that part of the specimen. Based on past experience, however, sound concrete can easily withstand these conditions. This is can also occur in the field under certain circumstances.

MACHINE LAYOUT

The machine holds up to sixteen prism specimens (plus two prisms for temperature control), seven and one-half by ten by forty centimeters (3 × 4 × 16 inches). The specimens are placed lengthwise in a stainless steel compartment, open on top, forty-one and one-half centimeters ($16^1/_2$ inches) long, eight and one-quarter centimeters ($3^1/_4$ inches) wide and eleven centimeters ($4^3/_8$ inches) deep. The interior dimension allows approximately three millimeters ($^1/_8$ inch) on each side of the specimen when a spacer is added. C 666 *requires* a maximum of three millimeters ($^1/_8$ inch) and a minimum of one millimeter ($^1/_{32}$ inch) of water around the specimen. So it is important that the specimen dimensions be tightly controlled to meet the test standard. The prisms sit on a Z-shaped length of brass rod to provide clearance underneath. The compartments sit flat on a water-saturated velvet cloth over a refrigeration platform, with heating elements between each compartment and on each end. The compartments are held in place by stainless steel clips; these clips also secure the position of the heating elements and provide positive contact between the elements and the specimen compartments. When the prisms are placed in the compartment, that space is filled with water and the top of the concrete is also covered with a maximum of three millimeters ($^1/_8$ inch) of water. A drain in the bottom of the cabinet handles overflow. A bucket is placed at the end of a flexible tube attached to the drain to collect the excess water.

Heat transfer between the compartments and heating and refrigeration systems is direct. The fourth and fifteenth compartments each contain a temperature probe placed in a concrete specimen (see Figure 5). The outputs of these probes are averaged to determine the temperature of the specimens. The changeover points for the heating and cooling phases are at -17.8 and 4.4°C. A thermal limit relay (provided by the manufacturer) is built into the heating system to prevent the temperature in the cabinet from rising too high in the event of a malfunction. It can be set to a desired temperature limit and is normally at the 30°C position.

The refrigeration system sits on a platform underneath the cabinet. There is a sight glass mounted in one of the pressure lines. The lines run from the system through the bottom of the cabinet to connect to the coils inside the platform on which the specimens rest. The heating system consists of a thermal limit relay and nineteen heating elements. Each element has its own plug, which is plugged into a line outlet and are raised from the platform by two lengths of aluminum U-beams running the length of the platform. The relays, refrigeration system cutoff switch and circuit breakers are mounted on the side of the cabinet near the refrigeration system. Photos and diagrams of the machine exterior controls and interior layout follow (Figures 1 through 6). All of the components run at 115 VAC (the heating elements are rated for 250V, but running at the lower voltage greatly extends the life). Data for the control temperatures during cycles is also included (see Appendix F); this confirms that the machine meets ASTM C 666 specifications (except during the initial freezing phase, but that is to be expected). The temperatures shown are for the center of the two probe specimens. C 666 requires that the temperature not vary by more than 3.3°C on any point on the surface of any specimens. Since the temperature at the center of the specimens lag behind that on the surface, it can be accepted that the surface temperatures varies less than the interior temperatures. C 666 also makes provisions for greater temperature variations during changeover (no value is specified); as the greatest variation (~3°C) is near the low changeover point, this indicates that the machine is within the requirements.

Figure 1 – Interior of Freeze/Thaw Cabinet

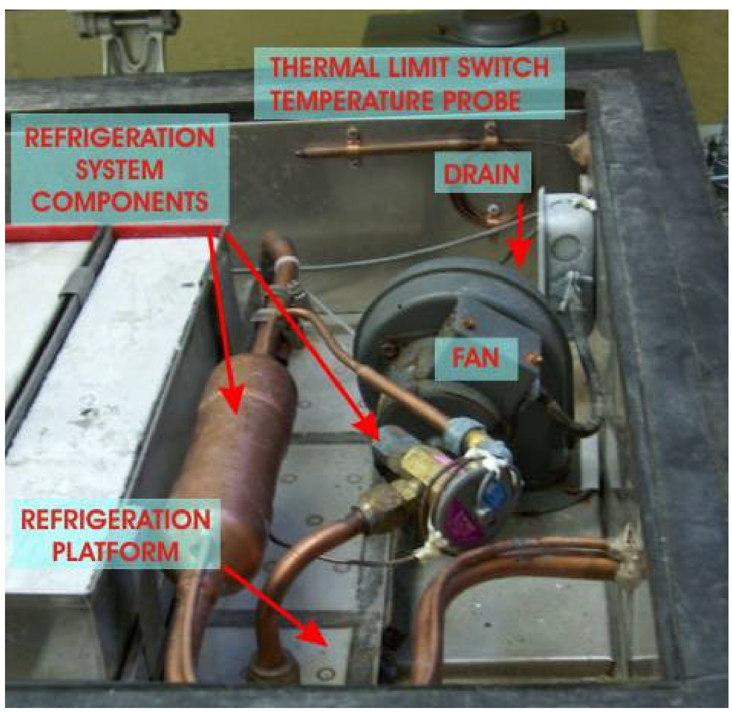

Figure 2 – Interior Cabinet Components

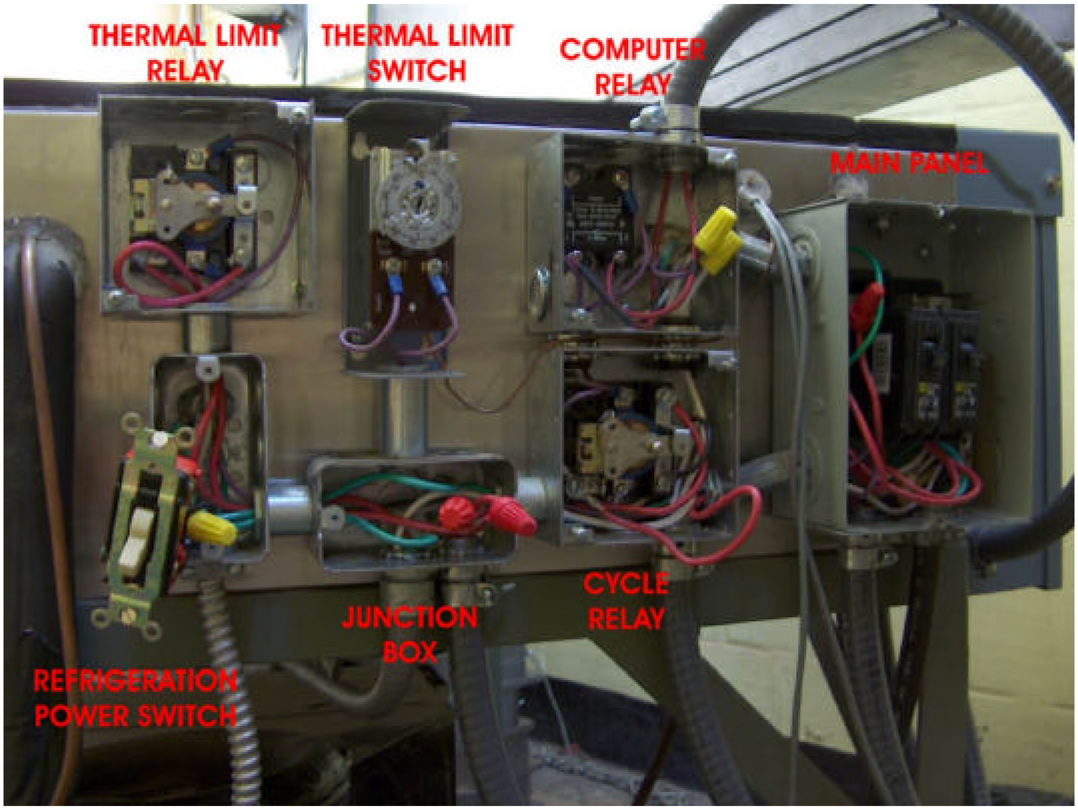

Figure 3 – Machine Control Elements

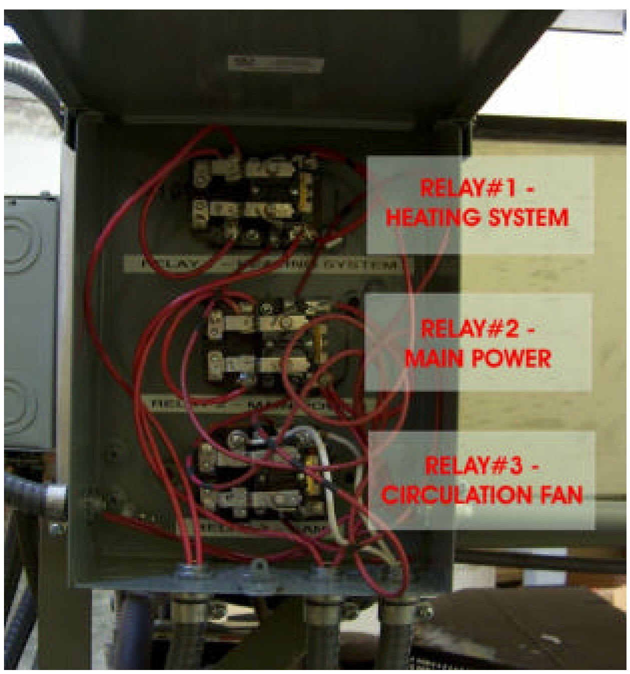

Figure 4 – Computer Interface Relays

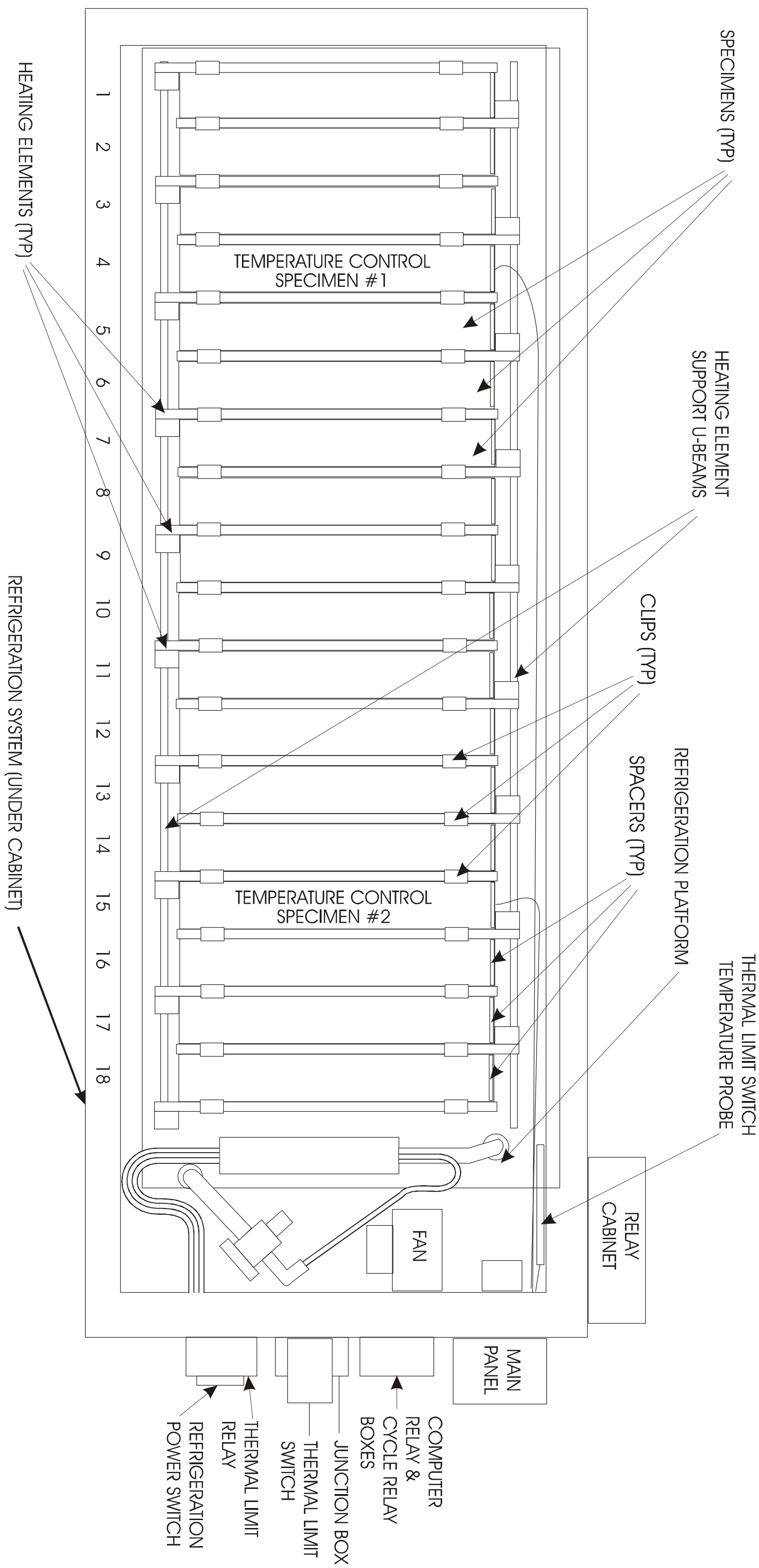

Figure 5 – Cabinet Interior Layout

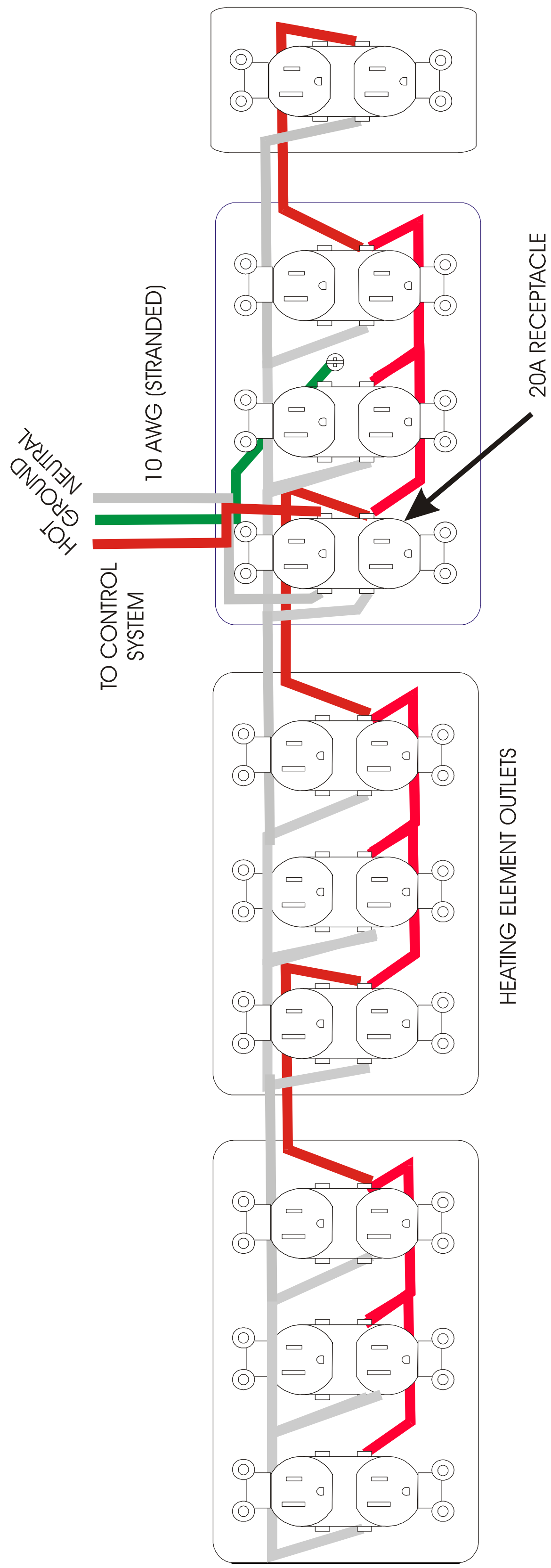

Figure 6 – Heating Element Outlet Wiring

ELECTRONIC CONTROL SYSTEM

The system consists of five major elements: the controlling computer, analog/digital I/O board plugged into the computer, the relay board used for digital output, the temperature probes, the circuit board that converts the probe output into voltages to feed to the analog inputs of the I/O board. Wiring schematics are detailed in Appendix C.

The computer can be any standard DOS/x86-based computer with a standard ISA bus and 40 MB or larger hard drive (provided the computer BIOS can recognize large capacity drives). The CPU can be almost anything (286 and higher, although higher level 686 class processors and above systems will not have ISA slots). The demands on it are not especially great.

The input/output (I/O) board is an Advantech PCL-711B and it plugs into a bus slot on the computer. It has eight analog inputs (A/D) two of which are used; one analog output (D/A), which is used to drive the strip chart recorder; sixteen digital inputs (D/I), none of which are used; sixteen digital outputs D/O), five of which are used. The analog inputs and outputs are connected to the I/O board using a PCL-7115 terminal board. Advantech supplied driver programs to access the various I/O functions, which were then incorporated into a program to operate the machine. The manual for the board is included on the CD-ROM accompanying this manual. Appendix G has the contents of the disc.

The PCLD-786 relay board is fed from the I/O board. It then controls the electric power fed to five relays, either directly on D/O channels eight through fifteen or through solid state relays (SSR) on D/O channels zero through seven :

1] The relay connected to channel zero controls power to the heating system.
2] The relay connected to channel one controls power to the strip chart recorder motor.
3] The relay connected to channel two controls power to the main line into the machine.
4] The relay connected to channel three controls power to the circulation fan.
5] The relay connected to channel eight controls the cycling relay on the machine (when the relay is actuated, the refrigeration system is powered; otherwise, the heating system is on). This is done through the five volt DC relay provided by the machine manufacturer.

The power for channels zero through three are fed from an external 120 volt line, jumpered from channel to channel. The power for channel eight requires only five volts and is supplied by the computer. The manual for this board is also included on the CD-ROM.

The temperature probes are 2N2222 transistors, with the base and emitter shorted (Appendix B contains the details of their fabrication). Their electrical characteristics vary with temperature, which is used to determine their temperature and hence, the temperature of their surroundings.

The probes are attached to a circuit board which converts the output to a voltage which can be read by the I/O board (Appendix C has a schematic of the circuit and an explanation of its function is in Appendix D). The board has precision potentiometers for set point and gain to calibrate the temperature probes. A regulated nominal twelve volt power supply feeds the circuit board. The outputs of the circuit are connected to a terminal board provided with the 711B and feed A/D channels zero and one. Up to six additional probes can be connected. The D/A channel feeds a signal to the strip chart recorder stylus movement from the same terminal board. The recorder is a Rustrak Model 288, 115V@60 Hz. The peak input voltage for the stylus is 100 mV. The paper roll advances one inch/hour and is marked in twelve hour time. The paper should be set to the time the cycling is started each time. While the data is recorded on the computer, the recorder provides a backup, as well as an easily accessible check of the temperature/time history. Setting the paper to track actual time allows the operator to see when events occurred. This would include the beginning and ending of phases and also anomalous events, such as failure of the heating or cooling system or the machine power.

It is strongly recommended that an uninterruptible power supply (UPS) be used for the computer, the twelve volt power supply and the recorder. In the event of a power outage, a 600 VA or higher unit will keep a low end computer (such as one suitable for controlling the machine) running for at least 30 minutes. In the event of a minor outage, this will allow the test to continue with minimal effect. Many power losses last for less than a second, but that would still be enough to force the computer to reboot without a UPS. The control system will continue to track the temperature of the probes and if power is restored before the UPS batteries discharge, normal operation will resume. A UPS will also provide some surge protection for the attached components.

OPERATING INSTRUCTIONS

The machine uses a 115 volt AC circuit, rated at 30 amps. Saturate the velvet cloth on the top of the refrigeration platform with water. Place each of the specimens in a compartment, with the “Z” rod at the bottom and fit one of the red plastic spacers in at one end. Set the compartments on the platform, with a heating element in between each compartment and with the heating elements covered with stainless steel sheaths at each end. Fit the clips over the top the compartment walls and push all the way down to secure everything in place. Fill the compartment with water to a height of six millimeters over the highest point on the specimen. If less than sixteen test specimens are to be tested, compartments may be filled with other prisms to act as "dummy " specimens, to make up the difference in thermal mass. The specimens should be placed in the tank in a random order. The supplied chart (at the end of this manual) may be photocopied or printed from the CD-ROM and used to track specimen position. Note: the specimens should be rotated along the long axis after every inspection so that each face alternates facing upwards. This helps average the effects of the freezing and thawing throughout the specimens. Note that while working inside the test chamber, the heavy link chain provided (not the lighter one attached to the side of the lid and the cabinet) must be used to snugly secure the lid to the support frame. The lid is extremely heavy and does not otherwise lock in place. Severe injury could result if the lid were to close while someone is working inside the chamber.

THE OPERATING PROGRAM:

The machine is operated by a program on the hard drive of the computer and on the supplied disk (a hardcopy of the program is in Appendix E; it is also on the included CD-ROM). Test data is also written to the disk, which can then be manipulated for plotting and analysis. To run the program, perform the following steps:

1) Turn on the power for the computer and components. At this point, power should be supplied to the freeze/thaw machine (the power cord should be plugged in and the circuit breaker supplying power to the machine should be on, switches up).

4) At the "C:/" prompt, type in FT and press the ENTER key.

5) If everything has gone as planned, the title screen of the program should now appear. Press the ENTER key as requested. Type in the desired number of cycles and press the ENTER key again. Finally, press the Y key in response to "Are you ready to start the test now?" and then the ENTER key to start the test. From this point until the desired number of cycles are completed, the process should be completely automatic. Note the maximum number of cycles allow by the test method is 36, although lower numbers can be entered to allow scheduling of the inspection or at the end of the test to reach 300 cycles. Note that the machine normally completes about six cycles per day, although this can vary with environmental conditions in the room (C 666 allows a range of two to five hours, with at least 25% of the time for the heating phase). A lower temperature in the room will generally provide faster cycling, because the refrigeration system dumps heat as part of its function and cooler air around it will make it work more efficiently.

6) The computer display gives the current time, the time at which the cycle started and the time at which the phase (heating or cooling) started. The requested number of cycles is shown, as well as the current number of cycles elapsed. The total number of cycles for the entire test run is also shown. The probes temperatures are also shown, both individually and as an average (the average controls the cycling), as well as the current changeover points. A prompt to hit the S key is displayed at the bottom of the screen (see #7 below).

7) Should interruption of the normal machine process be necessary, the S key may be pressed at any time to halt program operation. This will give the operator three options:

    a) Alter the changeover points – the temperature change tends to lag behind at cycle changes, so the high and low points can be adjusted so that the specimens reach the end points but do not exceed the temperature ranges.

    b) Emergency shutdown - all power to the machine is halted; all operations in progress stop. This is only given as an option after the user chooses not to alter the changeover points.

    c) Return to program (no changes) - returns to the program at the point from which it left.

8) The program automatically saves all data to disk at the end of each cycle and offers the operator the option of ending the test or starting another series of cycles, when the current series is complete. It also offers the option of extending the heating cycle to fully thaw the specimens.

9) When the requested number of cycles is completed and no further testing is desired, the power to all of the components can just be shut off, with no harmful effects (one significant advantage to using DOS, instead of a Windows environment).

MAINTENANCE

Normally, the machine requires very little maintenance. The stainless steel shell is extremely durable and does not require any service. It is also effective at protecting the interior of the cabinet and the internal insulation. The seal around the lid should be checked regularly and replaced if signs of deterioration are noticed. For proper operation, both the machine and its controlling computer should be operated in an air conditioned room, maintained at 18 to 23°C. Air conditioning will be necessary even during colder weather. The Permagum sealant for holes passing through the wall of the test chamber stays pliable, but may need to be reworked into the holes periodically to maintain a tight seal.

The refrigeration system should be monitored by the gauge in the system (with the readings as given in the machine layout section) If the gauge reading is not satisfactory and the machine cycles seem to be running unusually long (over five hours for a full load of specimens or a ratio of greater than 3 to 1 for the cooling to heating phases), the refrigeration system may need service. There are also other temperature requirements that need to be monitored and are listed in C 666, section 5. Contact a professional refrigeration repair company to have the equipment examined. *Do not attempt repair of the refrigeration system!* Special training and equipment is required to work on refrigeration systems; the results could be hazardous to both you and the machine, if you do not have the necessary skills. The refrigeration power can be shut off quickly if needed by using the switch as shown in Figure 3.

The check on the heating elements is fairly simple. If the resistance across the elements is 105 ohms, ±5, they should function properly. The resistance can be measured by unplugging each element and reading across the two flat prongs on the plug. The wire of each element is marked with a number which corresponds with the position in the cabinet (#19 at the end near the outlets). The main breaker will disconnect power to the heating elements

In an emergency, power to the whole system can be disconnected by shutting off the computer and the associated control components. This should be avoided, if at all possible, to avoid corrupting the data file. Note that, per C 666, the specimens must be stored in the frozen condition if the test is interrupted for any significant length of time.

The probe temperatures can be checked using the program PROBECAL.BAS. The temperatures measured are based on the calibration equations used in the operational program. It is possible to recalibrate the probes (or calibrate new probes) using the procedure specified in Appendix D (the temperatures from the calibration program would then be somewhat inaccurate, but should still be serviceable and the calibration program provides the voltages as output; these values will be accurate).

Two additional thermocouple dataloggers are provided to track temperatures in other locations within the test chamber. These are standalone units and can be connected directly to a serial port to download data, using the supplied cable. The required software to download the data is included on the CD-ROM. Other dataloggers can be used in addition to or in place of these if available.

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Appendix A

Designation: C 666 – 97

Standard Test Method for Resistance of Concrete to Rapid Freezing and Thawing[1]

This standard is issued under the fixed designation C 666; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope

1.1 This test method covers the determination of the resistance of concrete specimens to rapidly repeated cycles of freezing and thawing in the laboratory by two different procedures: Procedure A, Rapid Freezing and Thawing in Water, and Procedure B, Rapid Freezing in Air and Thawing in Water. Both procedures are intended for use in determining the effects of variations in the properties of concrete on the resistance of the concrete to the freezing-and-thawing cycles specified in the particular procedure. Neither procedure is intended to provide a quantitative measure of the length of service that may be expected from a specific type of concrete.

1.2 The values stated in inch-pound units are to be regarded as the standard.

1.3 All material in this test method not specifically designated as belonging to Procedure A or Procedure B applies to either procedure.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

C 157 Test Method for Length Change of Hardened Hydraulic-Cement Mortar and Concrete[2]

C 192 Practice for Making and Curing Concrete Test Specimens in the Laboratory[2]

C 215 Test Method for Fundamental Transverse, Longitudinal, and Torsional Frequencies of Concrete Specimens[2]

C 233 Test Method for Testing Air-Entraining Admixtures for Concrete[2]

C 295 Guide for Petrographic Examination of Aggregates for Concrete[2]

C 341 Test Method for Length Change of Drilled or Sawed Specimens of Hydraulic-Cement Mortar and Concrete[2]

C 490 Practice for Use of Apparatus for Determination of Length Change of Hardened Cement Paste, Mortar, and Concrete[2]

C 494 Specification for Chemical Admixtures for Concrete[2]

C 670 Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials[2]

C 823 Practice for Examination and Sampling of Hardened Concrete in Constructions[2]

3. Significance and Use

3.1 As noted in the scope, the two procedures described in this test method are intended to determine the effects of variations in both properties and conditioning of concrete in the resistance to freezing and thawing cycles specified in the particular procedure. Specific applications include specified use in Specification C 494, Test Method C 233, and ranking of coarse aggregates as to their effect on concrete freeze-thaw durability, especially where soundness of the aggregate is questionable.

3.2 It is assumed that the procedures will have no significantly damaging effects on frost-resistant concrete which may be defined as (*1*) any concrete not critically saturated with water (that is, not sufficiently saturated to be damaged by freezing) and (*2*) concrete made with frost-resistant aggregates and having an adequate air-void system that has achieved appropriate maturity and thus will prevent critical saturation by water under common conditions.

3.3 If as a result of performance tests as described in this test method concrete is found to be relatively unaffected, it can be assumed that it was either not critically saturated, or was made with "sound" aggregates, a proper air-void system, and allowed to mature properly.

3.4 No relationship has been established between the resistance to cycles of freezing and thawing of specimens cut from hardened concrete and specimens prepared in the laboratory.

4. Apparatus

4.1 *Freezing-and-Thawing Apparatus*:

[1] This test method is under the jurisdiction of ASTM Committee C-9 on Concrete and Concrete Aggregates and is the direct responsibility of Subcommittee C09.67 on Resistance of Concrete to Its Environment.

Current edition approved June 10, 1997. Published June 1998. Originally published as C 666 – 71. Last previous edition C 666 – 92.

[2] *Annual Book of ASTM Standards*, Vol 04.02.

4.1.1 The freezing-and-thawing apparatus shall consist of a suitable chamber or chambers in which the specimens may be subjected to the specified freezing-and-thawing cycle, together with the necessary refrigerating and heating equipment and controls to produce continuously, and automatically, reproducible cycles within the specified temperature requirements. In the event that the equipment does not operate automatically, provision shall be made for either its continuous manual operation on a 24-h a day basis or for the storage of all specimens in a frozen condition when the equipment is not in operation.

4.1.2 The apparatus shall be so arranged that, except for necessary supports, each specimen is: (*1*) for Procedure A, completely surrounded by not less than 1/32 in. (1 mm) nor more than 1/8 in. (3 mm) of water at all times while it is being subjected to freezing-and-thawing cycles, or (*2*) for Procedure B, completely surrounded by air during the freezing phase of the cycle and by water during the thawing phase. Rigid containers, which have the potential to damage specimens, are not permitted. Length change specimens in vertical containers shall be supported in a manner to avoid damage to the gage studs.

NOTE 1—Experience has indicated that ice or water pressure, during freezing tests, particularly in equipment that uses air rather than a liquid as the heat transfer medium, can cause excessive damage to rigid metal containers, and possibly to the specimens therein. Results of tests during which bulging or other distortion of containers occurs should be interpreted with caution.

4.1.3 The temperature of the heat-exchanging medium shall be uniform within 6°F (3.3°C) throughout the specimen cabinet when measured at any given time, at any point on the surface of any specimen container for Procedure A or on the surface of any specimen for Procedure B, except during the transition between freezing and thawing and *vice versa*.

4.1.3.1 Support each specimen at the bottom of its container in such a way that the temperature of the heat-exchanging medium will not be transmitted directly through the bottom of the container to the full area of the bottom of the specimen, thereby subjecting it to conditions substantially different from the remainder of the specimen.

NOTE 2—A flat spiral of 1/8-in. (3-mm) wire placed in the bottom of the container has been found adequate for supporting specimens.

4.1.4 For Procedure B, it is not contemplated that the specimens will be kept in containers. The supports on which the specimens rest shall be such that they are not in contact with the full area of the supported side or end of the specimen, thereby subjecting this area to conditions substantially different from those imposed on the remainder of the specimen.

NOTE 3—The use of relatively open gratings, metal rods, or the edges of metal angles has been found adequate for supporting specimens, provided the heat-exchanging medium can circulate in the direction of the long axis of the rods or angles.

4.2 *Temperature-Measuring Equipment*, consisting of thermometers, resistance thermometers, or thermocouples, capable of measuring the temperature at various points within the specimen chamber and at the centers of control specimens to within 2°F (1.1°C).

4.3 *Dynamic Testing Apparatus*, conforming to the requirements of Test Method C 215.

4.4 *Optional Length Change Test Length Change Comparator*, conforming to the requirements of Specification C 490. When specimens longer than the nominal 11 1/4 in. (286 mm) length provided for in Specification C 490 are used for freeze-thaw tests, use an appropriate length reference bar, which otherwise meets the Specification C 490 requirements. Dial gage micrometers for use on these longer length change comparators shall meet the gradation interval and accuracy requirements for Specification C 490 for either the inch or millimetre calibration requirements. Prior to the start of measurements on any specimens, fix the comparator at an appropriate length to accommodate all of the specimens to be monitored for length change.

4.5 *Scales*, with a capacity approximately 50 % greater than the weight of the specimens and accurate to at least 0.01 lb (4.5 g) within the range of ±10 % of the specimen weight will be satisfactory.

4.6 *Tempering Tank*, with suitable provisions for maintaining the temperature of the test specimens in water, such that when removed from the tank and tested for fundamental transverse frequency and length change, the specimens will be maintained within −2°F and +4°F (−1.1°C and +2.2°C) of the target thaw temperature for specimens in the actual freezing-and-thawing cycle and equipment being used. The use of the specimen chamber in the freezing-and-thawing apparatus by stopping the apparatus at the end of the thawing cycle and holding the specimens in it shall be considered as meeting this requirement, provided the specimens are tested for fundamental transverse frequency within the above temperature range. It is required that the same target specimen thaw temperature be used throughout the testing of an individual specimen since a change in specimen temperature at the time of length measurement can affect the length of the specimen significantly.

5. Freezing-and-Thawing Cycle

5.1 Base conformity with the requirements for the freezing-and-thawing cycle on temperature measurements of control specimens of similar concrete to the specimens under test in which suitable temperature-measuring devices have been imbedded. Change the position of these control specimens frequently in such a way as to indicate the extremes of temperature variation at different locations in the specimen cabinet.

5.2 The nominal freezing-and-thawing cycle for both procedures of this test method shall consist of alternately lowering the temperature of the specimens from 40 to 0°F (4.4 to −17.8°C) and raising it from 0 to 40°F (−17.8 to 4.4°C) in not less than 2 nor more than 5 h. For Procedure A, not less than 25 % of the time shall be used for thawing, and for Procedure B, not less than 20 % of the time shall be used for thawing (Note 4). At the end of the cooling period the temperature at the centers of the specimens shall be 0± 3°F (−17.8 ± 1.7°C), and at the end of the heating period the temperature shall be 40 ± 3°F (4.4 ± 1.7°C), with no specimen at any time reaching a temperature lower than −3°F (−19.4°C) nor higher than 43°F (6.1°C). The time required for the temperature at the center of any single specimen to be reduced from 37 to 3°F (2.8 to − 16.1°C) shall be not less than one half of the length of the cooling period, and the time required for the temperature at the center of any single specimen to be raised from 3 to 37°F (−16.1 to 2.8°C) shall be not less than one half of the length of the heating period. For specimens to be compared with each other, the time required to change the temperature at the centers of any specimens from 35 to 10°F (1.7 to − 12.2°C) shall not differ by more than one sixth of the length of the cooling period from the time required for any specimen and the time required to change the temperature at the centers of any specimens from 10 to 35°F (−12.2 to 1.7°C) shall not differ by more than one third of the length of the heating period from the time required for any specimen.

NOTE 4—In most cases, uniform temperature and time conditions can be controlled most conveniently by maintaining a capacity load of specimens in the equipment at all times. In the event that a capacity load of test specimens is not available, dummy specimens can be used to fill empty spaces. This procedure also assists greatly in maintaining uniform fluid level conditions in the specimen and solution tanks.

The testing of concrete specimens composed of widely varying materials or with widely varying thermal properties, in the same equipment at the same time, may not permit adherence to the time-temperature requirements for all specimens. It is advisable that such specimens be tested at different times and that appropriate adjustments be made to the equipment.

5.3 The difference between the temperature at the center of a specimen and the temperature at its surface shall at no time exceed 50°F (27.8°C).

5.4 The period of transition between the freezing-and-thawing phases of the cycle shall not exceed 10 min, except when specimens are being tested in accordance with 8.3.

6. Sampling

6.1 Constituent materials for concrete specimens made in the laboratory shall be sampled using applicable standard methods.

6.2 Samples cut from hardened concrete are to be obtained in accordance with Practice C 823.

7. Test Specimens

7.1 The specimens for use in this test method shall be prisms or cylinders made and cured in accordance with the applicable requirements of Practice C 192 and Specification C 490.

7.2 Specimens used shall not be less than 3 in. (76 mm) nor more than 5 in. (127 mm) in width, depth, or diameter, and not less than 11 in. (279 mm) nor more than 16 in. (406 mm) in length.

7.3 Test specimens may also be cores or prisms cut from hardened concrete. If so, the specimens should not be allowed to dry to a moisture condition below that of the structure from which taken. This may be accomplished by wrapping in plastic or by other suitable means. The specimens so obtained shall be furnished with gage studs in accordance with Test Method C 341.

7.4 For this test the specimens shall be stored in saturated lime water from the time of their removal from the molds until the time freezing-and-thawing tests are started. All specimens to be compared with each other initially shall be of the same nominal dimensions.

8. Procedure

8.1 Molded beam specimens shall be cured for 14 days prior to testing unless otherwise specified. Beam specimens sawed from hardened concrete shall be moisture-conditioned by immersing in saturated lime water at 73.4 ± 3°F (23 ± 1.7°C) for 48 h prior to testing unless otherwise specified.

8.2 Immediately after the specified curing or conditioning period, bring the specimen to a temperature within − 2°F and + 4°F (−1.1°C and + 2.2°C) of the target thaw temperature that will be used in the freeze-thaw cycle and test for fundamental transverse frequency, weigh, determine the average length and cross section dimensions of the concrete specimen within the tolerance required in Test Method C 215, and determine the initial length comparator reading (optional) for the specimen with the length change comparator. Protect the specimens against loss of moisture between the time of removal from curing and the start of the freezing-and-thawing cycles.

8.3 Start freezing-and-thawing tests by placing the specimens in the thawing water at the beginning of the thawing phase of the cycle. Remove the specimens from the apparatus, in a thawed condition, at intervals not exceeding 36 cycles of exposure to the freezing-and-thawing cycles, test for fundamental transverse frequency and measure length change (optional) with the specimens within the temperature range specified for the tempering tank in 4.6, weigh each specimen, and return them to the apparatus. To ensure that the specimens are completely thawed and at the specified temperature place them in the tempering tank or hold them at the end of the thaw cycle in the freezing-and-thawing apparatus for a sufficient time for this condition to be attained throughout each specimen to be tested. Protect the specimens against loss of moisture while out of the apparatus and turn them end-for-end when returned. For Procedure A, rinse out the container and add clean water. Return the specimens either to random positions in the apparatus or to positions according to some predetermined rotation scheme that will ensure that each specimen that continues under test for any length of time is subjected to conditions in all parts of the freezing apparatus. Continue each specimen in the test until it has been subjected to 300 cycles or until its relative dynamic modulus of elasticity reaches 60 % of the initial modulus, whichever occurs first, unless other limits are specified (Note 5). For the optional length change test, 0.10 % expansion may be used as the end of test. Whenever a specimen is removed because of failure, replace it for the remainder of the test by a dummy specimen. Each time the specimen is tested for fundamental frequency (Note 6) and length change, make a note of its visual appearance and make special comment on any defects that develop (Note 7). When it is anticipated that specimens may deteriorate rapidly, they should be tested for fundamental transverse frequency and length change (optional) at intervals not exceeding 10 cycles when initially subjected to freezing and thawing.

NOTE 5—It is not recommended that specimens be continued in the test after their relative dynamic modulus of elasticity has fallen below 50 %.

NOTE 6—It is recommended that the fundamental longitudinal frequency be determined initially and as a check whenever a question exists concerning the accuracy of determination of fundamental transverse frequency, and that the fundamental torsional frequency be determined initially and periodically as a check on the value of Poisson's ratio.

NOTE 7—In some applications, such as airfield pavements and other slabs, popouts may be defects that are a concern. A popout is characterized by the breaking away of a small portion of the concrete surface due to internal pressure, thereby leaving a shallow and typically conical spall in the surface of the concrete through the aggregate particle. Popouts may be observed as defects in the test specimens. Where popouts are a concern, the number and general description should be reported as a special comment. The aggregates causing the popout may be identified by petrographic examination as in Practice C 295.

8.4 When the sequence of freezing-and-thawing cycles must be interrupted store the specimens in a frozen condition.

NOTE 8—If, due to equipment breakdown or for other reasons, it becomes necessary to interrupt the cycles for a protracted period, store the specimens in a frozen condition in such a way as to prevent loss of moisture. For Procedure A, maintain the specimens in the containers and surround them by ice, if possible. If it is not possible to store the specimens in their containers, wrap and seal them, in as wet a condition as possible, in moisture-proof material to prevent dehydration and store in a refrigerator or cold room maintained at 0 ± 3°F (−17.8 ± 1.7°C). Follow the latter procedure when Procedure B is being used. In general, for specimens to remain in a thawed condition for more than two cycles is undesirable, but a longer period may be permissible if this occurs only once or twice during a complete test.

9. Calculation

9.1 *Relative Dynamic Modulus of Elasticity*—Calculate the numerical values of relative dynamic modulus of elasticity as follows:

$$P_c = (n_1^2/n^2) \times 100 \tag{1}$$

where:

P_c = relative dynamic modulus of elasticity, after c cycles of freezing and thawing, percent,
n = fundamental transverse frequency at 0 cycles of freezing and thawing, and
n_1 = fundamental transverse frequency after c cycles of freezing and thawing.

NOTE 9—This calculation of relative dynamic modulus of elasticity is based on the assumption that the weight and dimensions of the specimen remain constant throughout the test. This assumption is not true in many cases due to disintegration of the specimen. However, if the test is to be used to make comparisons between the relative dynamic moduli of different specimens or of different concrete formulations, P_c as defined is adequate for the purpose.

9.2 *Durability Factor*—Calculate the durability factor as follows:

$$DF = PN/M \tag{2}$$

where:

DF = durability factor of the test specimen,
P = relative dynamic modulus of elasticity at N cycles, %,
N = number of cycles at which P reaches the specified minimum value for discontinuing the test or the specified number of cycles at which the exposure is to be terminated, whichever is less, and
M = specified number of cycles at which the exposure is to be terminated.

9.3 *Length Change in Percent (optional)*—Calculate the length change as follows:

$$L_c = \frac{(l_2 - l_1)}{L_g} \times 100 \tag{3}$$

where:

L_c = length change of the test specimen after C cycles of freezing and thawing, %,
l_1 = length comparator reading at 0 cycles,
l_2 = length comparator reading after C cycles, and
L_g = the effective gage length between the innermost ends of the gage studs as shown in the mold diagram in Specification C 490.

10. Report

10.1 Report the following data such as are pertinent to the variables or combination of variables studied in the tests:

10.2 *Properties of Concrete Mixture*:

10.2.1 Type and proportions of cement, fine aggregate, and coarse aggregate, including maximum size and grading (or designated grading indices), and ratio of net water content to cement,

10.2.2 Kind and proportion of any addition or admixture used,

10.2.3 Air content of fresh concrete,

10.2.4 Unit weight of fresh concrete,

10.2.5 Consistency of fresh concrete,

10.2.6 Air content of the hardened concrete, when available,

10.2.7 Indicate if the test specimens are cut from hardened concrete, and if so, state the size, shape, orientation of the specimens in the structure, and any other pertinent information available, and

10.2.8 Curing period.

10.3 *Mixing, Molding, and Curing Procedures*—Report any departures from the standard procedures for mixing, molding, and curing as prescribed in Section 7.

10.4 *Procedure*—Report which of the two procedures was used.

10.5 *Characteristics of Test Specimens*:

10.5.1 Dimensions of specimens at 0 cycles of freezing and thawing,

10.5.2 Weight of specimens at 0 cycles of freezing and thawing,

10.5.3 Nominal gage length between embedded ends of gage studs, and

10.5.4 Any defects in each specimen present at 0 cycles of freezing and thawing.

10.6 *Results*:

10.6.1 Values for the durability factor of each specimen, calculated to the nearest whole number, and for the average durability factor for each group of similar specimens, also calculated to the nearest whole number, and the specified values for minimum relative dynamic modulus and maximum number of cycles (Note 9),

10.6.2 Values for the percent length change of each specimen and for the average percent length change for each group of similar specimens (Note 10),

10.6.3 Values of weight loss or gain for each specimen and average values for each group of similar specimens, and

10.6.4 Any defects in each specimen which develop during testing, and the number of cycles at which such defects were noted.

NOTE 10—It is recommended that the results of the test on each specimen, and the average of the results on each group of similar specimens, be plotted as curves showing the value of relative modulus of elasticity or percent length change against time expressed as the number of cycles of freezing and thawing.

11. Precision and Bias

11.1 *Dynamic Modulus*:

11.1.1 *Within-Laboratory Precision (Single Beams)*—Criteria for judging the acceptability of durability factor results obtained by the two procedures in the same laboratory on concrete specimens made from the same batch of concrete or from two batches made with the same materials are given in Table 1. Precision data for length change (optional) are not available at this time.

NOTE 11—The between-batch precision of durability factors has been found to be the same as the within-batch precision. Thus the limits given in this precision statement apply to specimens from different batches made with the same materials and mix design and having the same air content as well as to specimens from the same batch.

NOTE 12—The precision of this method for both procedures has been found to depend primarily on the average durability factor and not on the maximum N or minimum P specified for terminating the test nor on the size of the beams within limits. The data on which these precision statements are based cover maximum N's from 100 to 300 cycles, and minimum P's from 50 to 70 percent of E_0. The indexes of precision are thus valid at least over these ranges.

TABLE 1 Within-Laboratory Durability Factor Precision for Single Beams

NOTE 1—The values given in Columns 2 and 4 are the standard deviations that have been found to be appropriate for Procedures A and B, respectively, for tests for which the average durability factor is in the corresponding range given in Column 1. The values given in Columns 3 and 5 are the corresponding limits that should not be exceeded by the difference between the results of two single test beams.

Range of Average Durability Factor	Procedure A		Procedure B	
	Standard Deviation[A]	Acceptable Range of Two Results[A]	Standard Deviation[A]	Acceptable Range of Two Results[A]
0 to 5	0.8	2.2	1.1	3.0
5 to 10	1.5	4.4	4.0	11.4
10 to 20	5.9	16.7	8.1	22.9
20 to 30	8.4	23.6	10.5	29.8
30 to 50	12.7	35.9	15.4	43.5
50 to 70	15.3	43.2	20.1	56.9
70 to 80	11.6	32.7	17.1	48.3
80 to 90	5.7	16.0	8.8	24.9
90 to 95	2.1	6.0	3.9	11.0
Over 95	1.1	3.1	2.0	5.7

[A] These numbers represent the (1S) and (D2S) limits as described in Practice C 670.

11.1.1.1 The different specimen sizes represented by the data include the following: 3 by 3 by 16-in; 3 by 3 by 16¼-in.; 3 by 4 by 16-in.; 3½ by 4½ by 16-in.; 3 by 3 by 11-in.; and 3½ by 4 by 16-in.; and 4 by 3 by 16-in. The first dimension given represents the direction in which the specimens were vibrated in the test for fundamental transverse frequency. The most commonly used size was 3 by 4 by 16-in.

11.1.2 *Within-Laboratory Precision (Averages of Two or More Beams)*—Specifications sometimes call for comparisons between averages of two or more beams. Tables 2 and 3 give appropriate standard deviations and acceptable ranges for the two procedures for two averages of the number of test beams shown.

11.1.3 *Multilaboratory Precision*—No data are available for evaluation of multilaboratory precision. It is believed that a multilaboratory statement of precision is not appropriate because of the limited possibility that two or more laboratories will be performing freezing-and-thawing tests on the same concretes.

11.2 *Length Change*:

11.2.1 *Within-Laboratory Precision*—The single operator coefficient of variation has been determined to be 29.9 %. Therefore, results of two properly conducted tests by the same operator on samples from the same batch of concrete, using the same freeze-thaw apparatus and the same length comparator, should not differ from each other by more than 84.6 % of the average.

11.2.2 *Multilaboratory Precision*—No data are available for multilaboratory precision. It is believed that a multilaboratory statement of precision is not appropriate because of the limited possibility that two or more laboratories will be performing freezing-and-thawing tests on the same concretes.

11.3 *Bias*—This test method has no bias because the values determined can be defined only in terms of this test method.[3]

12. Keywords

12.1 accelerated testing; concrete-weathering tests; conditioning; freezing and thawing; resistance-frost

[3] Supporting data for the precision statement for length change have been filed at ASTM Headquarters and may be obtained by requesting C9:1017.

TABLE 2 Within-Laboratory Durability Factor Precision for Averages of Two or More Beams—Procedure A

Range of Average Durability Factor	Number of Beams Averaged: 2		3		4		5		6	
	Standard Deviation[A]	Acceptable Range[A]	Standard Deviation[A]	Acceptable Range[A]	Standard Deviation[A]	Acceptable Range[A]	Standard Deviation[A]	Acceptable Range[A]	Standard Deviation[A]	Acceptable Range[A]
0 to 5	0.6	1.6	0.5	1.3	0.4	1.1	0.4	1.0	0.3	0.9
5 to 10	1.1	3.1	0.9	2.5	0.8	2.2	0.7	2.0	0.6	1.8
10 to 20	4.2	11.8	3.4	9.7	3.0	8.4	2.7	7.5	2.4	6.8
20 to 30	5.9	16.7	4.8	13.7	4.2	11.8	3.7	10.6	3.4	9.7
30 to 50	9.0	25.4	7.4	20.8	6.4	18.0	5.7	16.1	5.2	14.7
50 to 70	10.8	30.6	8.8	25.0	7.6	21.6	6.8	19.3	6.2	17.6
70 to 80	8.2	23.1	6.7	18.9	5.8	16.4	5.2	14.6	4.7	13.4
80 to 90	4.0	11.3	3.3	9.2	2.8	8.0	2.5	7.2	2.3	6.5
90 to 95	1.5	4.2	1.2	3.5	1.1	3.0	0.9	2.7	0.9	2.4
Above 95	0.8	2.2	0.6	1.8	0.5	1.5	0.5	1.4	0.4	1.3

[A] These numbers represent the (1S) and (D2S) limits as described in Practice C 670.

TABLE 3 Within-Laboratory Durability Factor Precision for Averages of Two or More Beams—Procedure B

Range of Average Durability Factor	Number of Beams Averaged: 2		3		4		5		6	
	Standard Deviation[A]	Acceptable Range[A]	Standard Deviation[A]	Acceptable Range[A]	Standard Deviation[A]	Acceptable Range[A]	Standard Deviation[A]	Acceptable Range[A]	Standard Deviation[A]	Acceptable Range[A]
0 to 5	0.8	2.1	0.6	1.8	0.5	1.5	0.5	1.4	0.4	1.2
5 to 10	2.9	8.1	2.3	6.6	2.0	5.7	1.8	5.1	1.7	4.7
10 to 20	5.7	16.2	4.7	13.2	4.1	11.5	3.6	10.3	3.3	7.4
20 to 30	7.4	21.0	6.1	17.2	5.3	14.9	4.7	13.3	4.3	12.2
30 to 50	10.9	30.8	8.9	25.1	7.7	21.8	6.9	19.5	6.3	17.8
50 to 70	14.2	40.2	11.6	32.9	10.1	28.5	9.0	25.5	8.2	23.2
70 to 80	12.1	34.2	9.9	27.9	8.5	24.2	7.6	11.6	7.0	19.7
80 to 90	6.2	17.6	5.0	14.4	4.4	12.5	3.9	11.1	3.6	10.2
90 to 95	2.8	7.8	2.3	6.4	2.0	5.5	1.7	4.9	1.6	4.5
Above 95	1.4	4.1	1.2	3.3	1.0	2.9	0.9	2.6	0.8	2.3

[A] These numbers represent the (1S) and (D2S) limits as described in Practice C 670.

APPENDIX B

Construction of Temperature Probe

The temperature probes are metal shell 2N2222 transistors. The base and emitter are shorted. The transistor leads are then soldered to the leads of four conductor flat telephone wire (green and red to the collector lead, black and yellow to the shorted base and emitter leads) and each lead is protected with one-sixteenth inch polyolefin heat shrink tubing. A clip-on heat sink *MUST* be attached to the lead being soldered to prevent damage to the transistor. Three and one-half inches of one-quarter inch polyolefin tubing is then shrunk over the transistor, leaving the top exposed (for optimum heat conduction) and extending along the flat wire. A one and one-half inch long by five-sixteenth inch outer diameter by one-half inch inner diameter plastic tube (the tube from a BIC pen is ideal) is filled with a high quality silicone adhesive sealant and pushed over the transistor. The sealant is forced into the tube to remove any air pockets. The excess sealant is wiped away, taking care to remove everything from the exposed face of the transistor. After the sealant cures for a full day, a one and three-eighth inch length of three-eighth inch heat shrink is placed around the tube and shrunk, once again leaving the face of the transistor exposed.

Transistor Data

Polarity :-	NPN
Material :-	Silicon
Package :-	TO18
Vcb Max (collector-base voltage rating with emitter open circuited) :-	60V
Vce Max (collector-emitter voltage rating with base open circuited) :-	30V
Veb Max (emitter-base voltage rating with collector open circuited) :-	5V
Ic Max (rated maximum collector current) :-	800mA
Tj Max (rated maximum junction temperature) :- 1	75C
Ptot (rated maximum device power dissipation) :-	500mWF
Ft Min (minimum common-emitter gain-bandwidth product):-	250M
Hfe (common emitter,short-circuit,current gain) :-	100mn
Hfe Bias (dc bias current at which Hfe measured):-	150mA
Applications use :-	Rf, Medium current, General purpose.

Appendix D details the calibration of the probes.

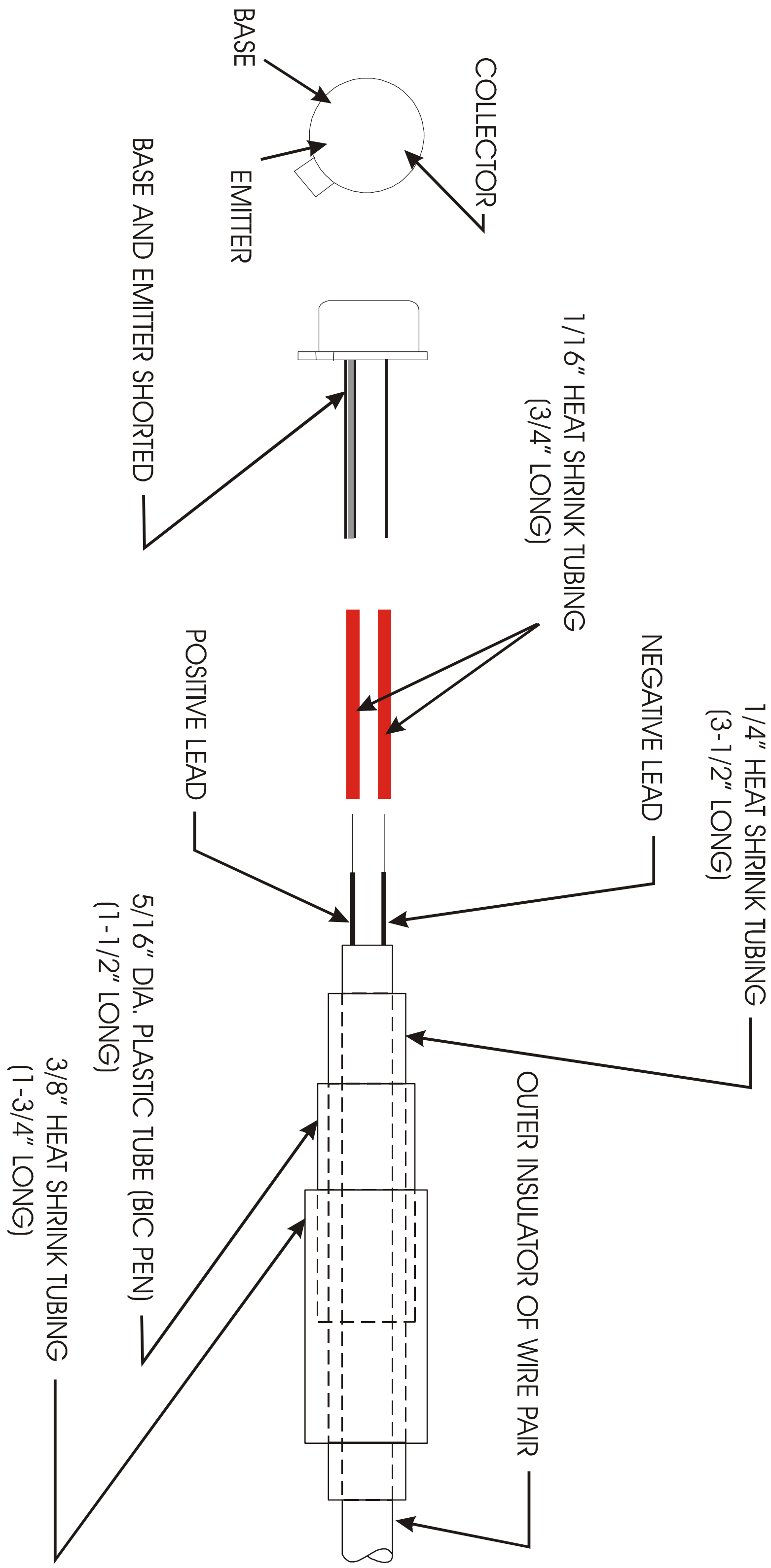

Figure B1 – Temperature Probe Construction

APPENDIX C
Computer Interface Control System

The following pages detail the wiring as modified to control the freeze/thaw machine by computer. Figure C3 shows the temperature probe drive control board. It is comprised of eight identical circuits, each centered around an operational amplifier, which takes the voltage difference across the 2N2222 transistors and applies gain to increase the voltage to a level that can be read by the a/d channels on the PCL-711b card.

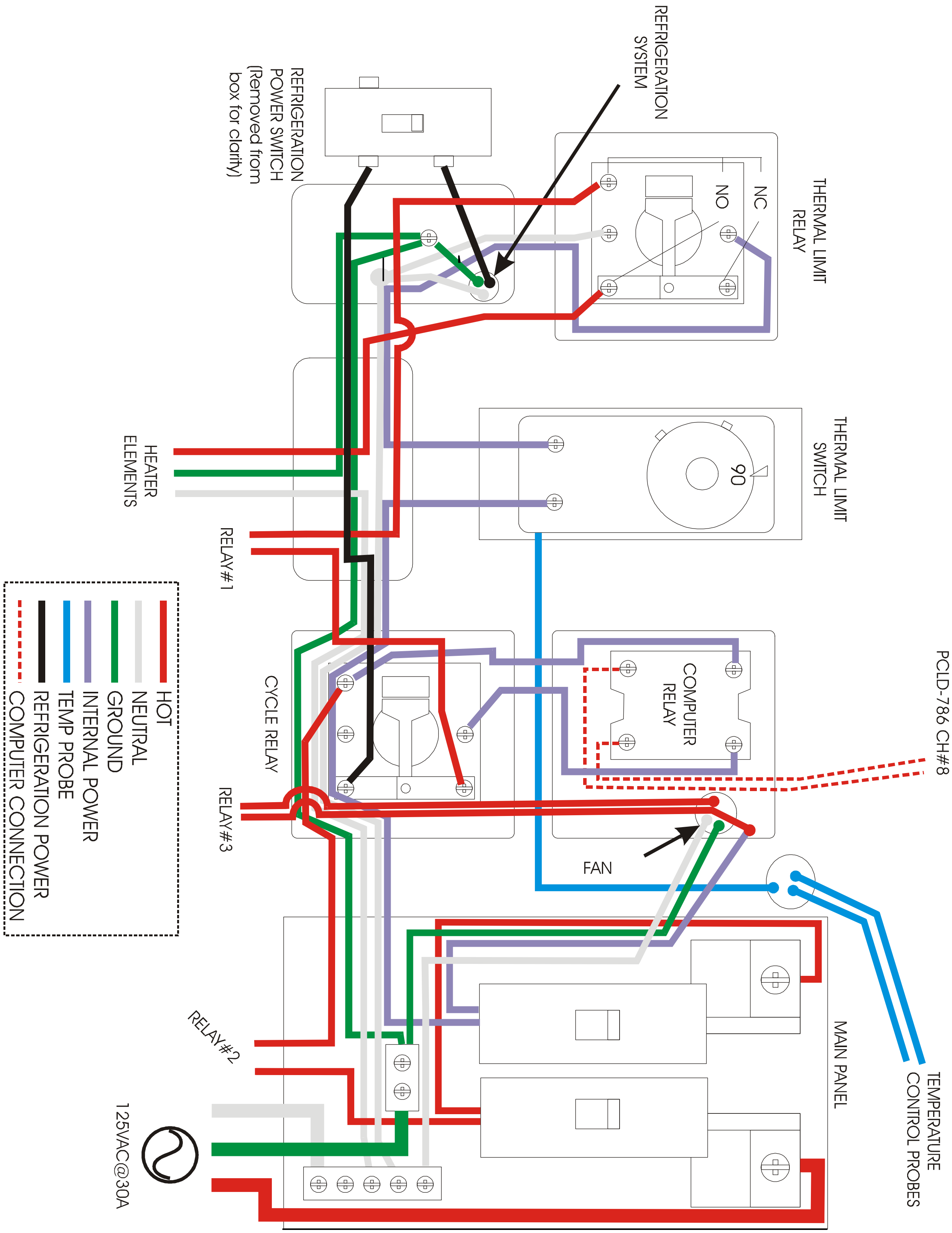

Figure C1 – Control System Schematic

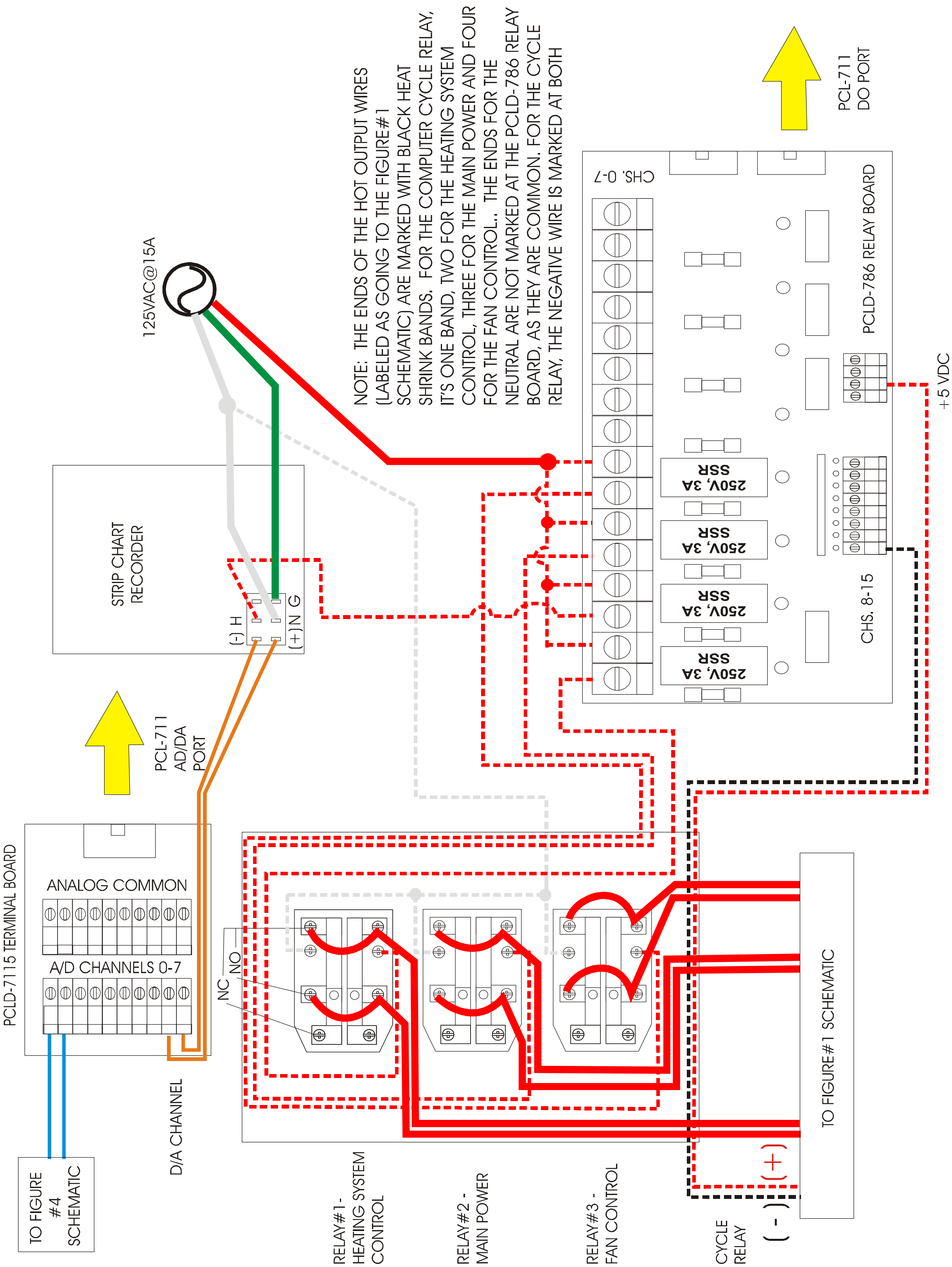

Figure C2 – Control Relay Schematic

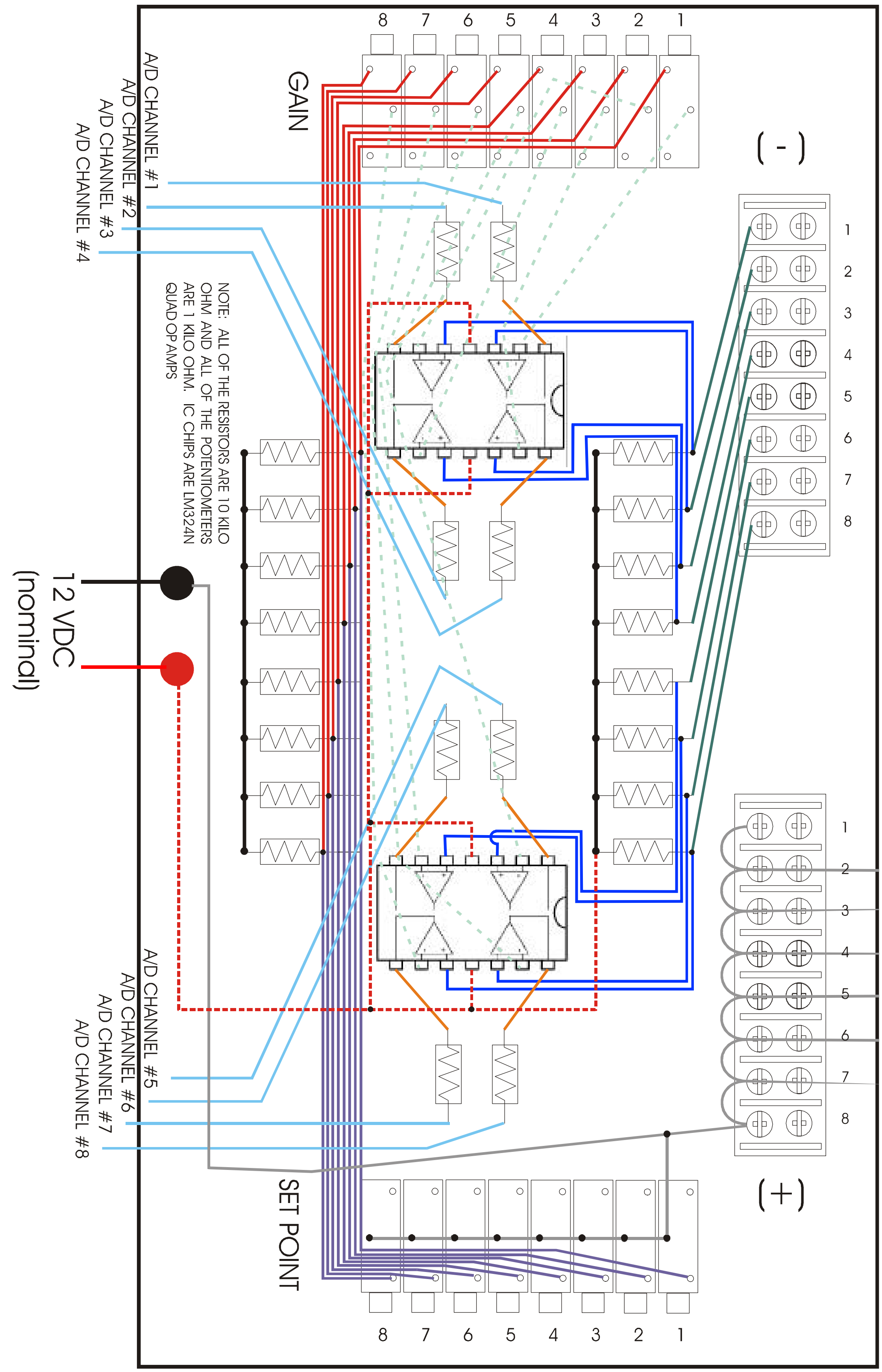

Figure C3 – Probe Driver Board Schematic

APPENDIX D

Probe Driver Board Construction and Probe Calibration

The driver circuit is a very simple design, shown in figure C3 (it may look complex, but it is only the same circuit duplicated eight times). There are two quad operational amplifiers (op amps), for a total of eight op amps. Each op amp has its own circuitry associated with it, and acts on only one probe (although there will be some interaction between channels in the circuit, since no special attempt was made to isolate them). The circuit is fed power through a regulated twelve volt power supply. The output voltage of the op amp is fed to one of analog inputs of the PCL-711b I/O board, referenced to ground. Each sub-circuit has two precision potentiometers. One pot adjusts the gain (amplification of the signal from the probe; this adjusts the voltage output range for the operational temperature range of the probe). The other adjusts the set point (the voltage output at a given probe reference temperature; generally 7°C). The probes are connected to the terminal blocks on the circuit board. The negative lead connects to the top block, the positive to the bottom. A series of eight wires (so numbered) are used to monitor the voltage output for the appropriate probe (again, referenced to the negative output of the power supply). Basic texts detailing the operation and design of op amps are available. However, understanding the theory behind the workings of the circuit is not necessary to use or repair the board, as the calibration instructions in Appendix D should be sufficient to operate the system and the schematic in Figure C3 lays out how to wire the board.

Calibration of the probes is time consuming, but not difficult. The probes are secured to the sensor for a digital thermometer. The combination is then immersed in a large bath of ethylene glycol (at least one gallon) which is then placed in a freezer. Connect the probes to the driver circuit and monitor the voltage at the outputs with a voltmeter. The calibration procedure is as follows (it must be performed for each sub-circuit):

1) Bring the bath temperature down to about -18°C.
2) After the voltage output stabilizes, adjust the gain to provide an output voltage of approximately four and one-half volts.
3) The bath temperature is then raised to 4°C (this can be accomplished by leaving the bath in the freezer but opening the door or lid and adjusting the freezer temperature control; it may take some experimentation to discover what setting and how much of an opening is required).
4) Again waiting for the voltage output to stabilize, adjust the set point such that the output voltage is about three volts.
5) Steps 1 through 3 are repeated until the voltages are maintained at the specified temperatures without readjustment.
6) Perform a linear regression to find the equation of the line describing the temperature vs. voltage relationship.
7) As a check, bring the bath temperature to -7°C (the process from step 3 can be used). After stabilization, measure the voltage. The equation should predict the temperature to within a degree or so.

The calibration temperatures do not have to be precisely as specified (-18 and 4°C are used because those are the changeover points of the machine and the probes should be as accurate as possible at those temperatures), but once chosen should be maintained as constant as possible throughout the calibration process. If that is not possible, the voltage variation at the proper gain is about five-hundredths of a volt per degree and that can be used to correct for different temperatures.

An initial comprehensive calibration was performed to determine the nature of the response curve of temperature versus voltage of the probes. The results are shown in Appendix F (note that these equations are not valid for the probes currently in use; they are shown only to demonstrate the form of calibration equation). The data points approximate a straight line over the range of -18 to 4°C. Therefore, a first order linear equation can be used to determine the temperature of the probes (as noted above) to within a plus or minus one-half degree tolerance. The current equations are incorporated into the operational program FTPROG.BAS in subroutine ADCONV. The equation constants are in the file CALIB.DAT (which has is set to a file attribute of "hidden"; this would have to changed using the DOS ATTRIB command; refer to the DOS manual for details) and can be changed if needed (if the probes are replaced). If this becomes necessary, the file should be copied to a backup file for safety's sake. When writing the new data in (using an ASCII text editor), *USE THE FORMAT OF THE ORIGINAL FILE!* Otherwise, the program may not be able to make use of the values properly.

APPENDIX E
Freeze/Thaw Machine Control Program

INPUTS:

1) Analog - Two (2) from temperature probes (transistors), one (1) in each of two (2) temperature control specimens and they are used to determine cycling of machine. The two values are averaged to determine the point of changeover. Up to six more analog inputs are available and may be used in the future to add probes to various locations in the machine and on its exterior. Note: provisions are made for adding up to six (6) additional probes and storing the temperature data. All that is required is to remove the apostrophes remarking out the appropriate progam lines.

2) Data inputs - The total elapsed cycles are inputted to the program from the disk at the start of each new set of cycles. The constants for the temperature probe calibration equations are also inputted to the program at this time.

OUTPUTS:

1) Digital - One (1) to the power input to the machine. One (1) to the heating system. One (1) to the circulation fan. One (1) to the strip chart recorder motor (see section 2). One (1) to the cycling relay that controls the heating and cooling phases

2) Analog - One (1) to the strip chart recorder, which acts as a backup system to record the temperatures in thermal control specimen.

MANIPULATION:

1) Probe inputs - All will be read as voltages; equations (developed from calibration) will be used to convert the voltages to the temperatures of the probes. At the low changeover point (typically -17°C), power will be sent to the main power, the heating system, the circulation fan and the strip chart recorder motor. This starts the heating phase. At the high changeover point (typically 2°C), power will be sent to main power, the cycling relay, the circulation fan and the strip chart recorder motor.

2) Cycling - The system will count the number of cycles (based on the number of low changeover points encountered) and put the machine on standby at an operator inputted value for the cycles (generally thirty-six).

3) Data outputs - All inputs are be saved to disk at intervals (to prevent the disk drive from operating constantly) for graphing and later analysis. The starting and ending times are recorded. The point of changeover is recorded to measure number of cycles.

Note: The program is written assuming that it and its data files are stored in drive C, in subdirectory "FTFILES".

```
'THIS PROGRAM CONTROLS THE SOILTEST CT-110 FREEZE/THAW MACHINE THROUGH AN INTERFACE WITH AN ADVENTECH
'  PCL-711B INTERFACE CARD, CAPABLE OF PERFORMING A/D AND D/A CONVERSIONS (8 CHANNELS OF INPUT AND 1 CHANNEL OF
'  OUTPUT, RESPECTIVELY) AND DIGITAL INPUT AND OUTPUT (16 CHANNELS OF EACH).  THERE ARE x TEMPERATURE PROBES
'  CONNECTED TO THE CARD (2N2222 TRANSISTORS, WITH THE EMITTER AND BASE SHORTED TOGETHER), WHOSE VALUES ARE
'  SAVED TO DISK AT SPECIFIC INTERVALS FOR LATER ANALYSIS.  TWO OF THE PROBES ARE PLACED IN TWO CONCRETE SPECIMENS IN
'  THE FOURTH AND FIFTEENTH POSITIONS IN THE MACHINE AND THEIR OUTPUT IS AVERAGED AND USED TO CONTROL THE MACHINE;
'  THAT IS, DETERMINE ITS MOMENT TO MOMENT OPERATING CHARACTERISTICS. THE OTHER SIX ARE USED TO MONITOR COOLANT
'  TEMPERATURES THROUGHOUT THE MACHINE.  THERE IS ONE OUTPUT (ANALOG) TO A STRIP CHART RECORDER, USED AS A BACKUP
'  MONITORING  SYSTEM.  ONE DIGITAL OUTPUT IS CONNECTED TO THE POWER FOR THE MACHINE (WHICH FEEDS TO THE HEATING AND
'  COOLING  SYSTEMS), ONE TO A RELAY THAT CYCLES THE MACHINE BETWEEN THE HEATING AND COOLING PHASES (WHICH CONTROLS
'  WHICH SYSTEM IS FED POWER), ONE TO A RELAY TO CONTROL POWER TO THE HEATING SYSTEM DIRECTLY (TO ALLOW THE HEATING
'  SYSTEM TO BE SHUT DOWN F THE SYSTEM TERMINATES ABNORMALLY (THIS IS A SAFETY FEATURE, IN ADDITION TO THE THERMAL
'  LIMIT SWITCH PROVIDED WITH THE MACHINE); OTHERWISE IT WOULD REMAIN ON UNTIL THE MACHINE IS SHUT DOWN), ONE TO A
'  RELAY THAT CONTROLS THE CIRCULATION FAN.  AND ONE IS CONNECTED (THROUGH AN EXTERNAL RELAY) TO THE STRIP CHART
'  RECORDER MOTOR TO ACTIVATE IT DURING CYCLING.

CLS
PRINT "-------------------------------------------------------------------------"
PRINT "|                                                                       |"
PRINT "|                                                                       |"
PRINT "|                                                                       |"
PRINT "|                             RIDOT                                     |"
PRINT "|              RESEARCH AND TECHNOLOGY DEVELOPMENT                      |"
PRINT "|                   LOGAN FREEZE/THAW MACHINE                           |"
PRINT "|                         CONTROL PROGRAM                               |"
PRINT "|                                                                       |"
PRINT "|                                                                       |"
PRINT "|                                                                       |"
PRINT "-------------------------------------------------------------------------"
LOCATE 14, 28
1 INPUT "PRESS ENTER TO CONTINUE", start$
CLS

'INPUT VARIABLES:
'    bcalx - Y-INTERCEPT OF GIVEN TEMPERATURE PROBE CALIBRATION EQUALTIONS.  READ FROM FILE CALIB.DAT
'    choice$ - INPUT FROM USER TO CONFIRM CHOICE OF OPTION.
'    high$ - ALLOWS THE OPERATOR TO CONFIRM A CAHNGE IN THE HIGH CHANGEOVER POINT (HIPOINT) IN SUBROUTINE BREAKOUT.
'    hipointnew - THE CHANGEOVER POINT IN øC FROM THE HEATING TO COOLING PHASE.  THIS VALUE IS CHOSEN BY THE
'       OPERATOR DURING THE SUBROUTINE BREAKOUT.  IF THE OPERATOR CONFIRMS THIS VALUE, HIPOINT IS SET EQUAL TO THIS
'       VALUE.
'    low$ - ALLOWS THE OPERATOR TO CONFIRM A CAHNGE IN THE LOW CHANGEOVER POINT (LOWPOINT) IN SUBROUTINE BREAKOUT.
'    lowpointnew - THE CHANGEOVER POINT IN øC FROM THE COOLING TO HEATING PHASE.  THIS VALUE IS CHOSEN BY THE
'       OPERATOR DURING THE SUBROUTINE BREAKOUT.  IF THE OPERATOR CONFIRMS THIS VALUE, LOWPOINT IS SET EQUAL TO THIS
'       VALUE.
'    nocycles - INPUT FROM OPERATOR TO SET THE NUMBER OF CYCLES THE MACHINE WILL RUN  BEFORE BEING PLACED
'         ON STANDBY.
```

```
'    mcalx - SLOPE OF GIVEN TEMPERATURE PROBE CALIBRATION EQUATIONS.  READ FROM FILE CALIB.DAT
'    power$ - ACTIVATES RELAY THAT FEEDS POWER TO MACHINE.
'    restart$ - INPUT FROM OPERATOR TO RESTART OR END TEST WHEN SPECIFIED NUMBER OF CYCLES ARE
'        COMPLETED (SEE NOCYCLES ABOVE).
'    rethaw$ - INPUT FROM OPERATOR TO ACTIVATE THAW SUBROUTINE OR CONTINUE WITHOUT THAWING
'    start$ - DUMMY VARIABLE TO START EXECUTION OF PROGRAM FUNCTIONS.
'    ttlcycle - INPUT FROM DATA FILE "TTLCYCLE.DAT", TOTAL ELAPSED CYCLES FOR TEST.  UPDATED DURING PROGRAM
'        EXECUTION.

'OUTPUT VARIABLES:
'    tempctrl - ARRAY CONTAINING ONE CYCLE OF RECORDED CONTROL TEMPERATURE VALUES AND TIMES (SAVED TO
'        DISK AND REINITIALIZED).
'    tempstore$ - ARRAY CONTAINING ONE CYCLE OF RECORDED TEST TANK TEMPERATURE VALUES AND
'        TIMES (SAVED TO DISK AND REINITIALIZED).

'INTERNAL VARIABLES:
'    coolend - RECORDS THE CURRENT VALUE OF ELAPSED (SEE BELOW) AT THE START OF THE HEATING CYCLE.  USED TO CALCULATE
'       THE RATIO OF HEATING TO COOLING PHASE TIMES.
'    cycle - TRACKS THE NUMBER OF CYCLES ELAPSED BETWEEN INSPECTIONS.
'    dat - SEE VARIABLE PHASE BELOW.
'    dat%(0), dat%(1), er%, fun% - VALUES USED BY PCL-711 DRIVER TO ACCESS FUNCTIONS ON  CARD.
'    elapsed - THE TIME IN SECONDS SINCE THE BEGINNING OF THE TEST (CALCULATED USING THE TIMER FUNCTION).
'    hipoint - THE CHANGEOVER POINT IN øC FROM THE HEATING TO COOLING PHASE.  ADJUSTABLE BY OPERATOR.
'    hitemp - THE HIGHEST TEMPERATURE REACHED DURING THE MOST RECENT CYCLE (øC).  TO ALLOW THE OPERATOR TO DETERMINE
'       THE OPTIMUM VALUE OF LOWPOINT INTERACTIVELY DURING MACHINE OPERATION.
'    hold$ - DIRECT KEYBOARD INPUT, ACTIVATES SUBROUTINE BREAKOUT.
'    hotend - RECORDS THE CURRENT VALUE OF ELAPSED (SEE ABOVE) AT THE START OF THE COOLING CYCLE.  USED TO CALCULATE
'       THE RATIO OF HEATING TO COOLING PHASE TIMES.
'    lowpoint - THE CHANGEOVER POINT IN øC FROM THE COOLING TO HEATING PHASE.  ADJUSTABLE BY OPERATOR.
'    lowtemp - THE LOWEST TEMPERATURE REACHED DURING THE MOST RECENT CYCLE (øC).  TO ALLOW THE OPERATOR TO DETERMINE
'       THE OPTIMUM VALUE OF LOWPOINT INTERACTIVELY DURING MACHINE OPERATION.
'    phase (dat) - INDICATES THE DESIRED CYCLING PHASE OF THE MACHINE.  THE PHASES ARE AS FOLLOWS (DAT IS THE
'       NUMBER FED TO THE SUBROUTINE DO; THE NUMBER IN PARENTHESES IS THE BINARY NUMBER THE PCL-711S DRIVER
'       USES; EACH ZERO INDICATES THAT POWER IS OFF FOR THAT CHANNEL, EACH ONE THAT POWER IS ON; THE FIRST NUMBER ON
'       THE RIGHT IS FOR MACHINE POWER, THE SECOND IS FOR THE RELAY THAT CONTROLS THE CYCLING, THE THIRD IS FOR THE
'       RELAY THAT ACTIVATES THE STRIP CHART RECORDER:
'           WHEN phase = 0 THEN dat = 0  (00000000), MACHINE SHUTDOWN.
'           WHEN phase = 1 THEN dat = 7  (100001110), FREEZING PHASE - MAIN POWER, CIRCULATION FAN,
'             STRIP CHART RECORDER AND CYCLE RELAY (TO ACTIVATE REFRIGERATION SYSTEM) FED POWER.
'           WHEN phase = 2 THEN dat = 5  (00000111), THAWING PHASE - MAIN POWER, CIRCULATION FAN,
'             STRIP CHART RECORDER AND HEATING ELEMENTS FED POWER.
'    phasetemp - HOLDS THE CURRENT PHASE OF THE MACHINE IN THE BREAKOUT SUBROUTINE.
'         SO THAT THE MACHINE MAY RETURN TO THAT PHASE IF THE USER DESIRES.
'    phasetemp$ - ACCESSES THE TIME$ FUNCTION WHEN PHASE STARTS AND STORES THAT TIME.
'    start - AN ARRAY CONTAINING THE STARTING TIMES FOR EACH CYCLE IN SECONDS ELAPSED (USING TIMER FUNCTION).
'    starttime$ - ACCESSES THE TIME$ FUNCTION WHEN CYCLE STARTS AND STORES THAT TIME.
```

```
'    temp1 TO temp8 - DATA ACCESSED FROM PCL-711B
'    tempnew - AVERAGE OF THE TEMPERATURE OF PROBES ONE AND TWO (THE CONTROL PROBES).
'    tempsum1 TO tempsum8 - SUM OF 100 SUCESSIVE VALUES OF TEMP1 TO TEMP8, RESPECTIVELY
'    tempold - THE PREVIOUS CONTROL TEMPERATURE, USED TO COMPENSATE FOR ATYPICAL VARIATIONS IN
'       THE MEASURED VALUES.  ALSO USED TO DERIVE VOLTAGE SENT TO STRIP CHART RECORDER.  TAKEN
'       FROM TEMPNEW.
'    thawtemp - THE AVERAGE TEMPERATURE OF THE CONTROL SPECIMENS DURING THE OPERATION OF THE
'       SUBROUTINE (CALCULATED BY ADCONV)
'    toarray - INDICATES WHEN THE AVERAGE TEMPERATURE OF THE CONTROL PROBES DROPS ONE øC TO
'       DETERMINE WHEN THE TEMPERATURE DATA SHOULD BE SAVED TO THE  ARRAYS

SUBROUTINES:

'    breakout - ALLOWS OPERATOR TO INTERRUPT PROGRAM EXECUTION AND CHANGE MODES
'    thaw - ALLOWS OPERATOR TO FULLY THAW SPECIMENS BY ACTIVATING HEATING PHASE (BRINGS CONTROL SPECIMEN TO
'        21.1 øC)
'    todisk - SAVES ALL TIME AND TEMPERATURE DATA TO DISK FILES

'SUBROUTINES BUILT AROUND PCL-711 DRIVER FUNCTIONS):
'    adconv - ACCESSES TEMPERATURE PROBE VOLTAGES FROM PCL-711AND CONVERTS THEM TO TEMPERATURES, BASED ON
'        CALIBRATION EQUATIONS
'    daconv - ACCESSES PCL-711 AND FEEDS  VOLTAGE TO STRIP CHART RECORDER, BASED ON AVERAGE VOLTAGES MEASURED
'        FROM TEMPERATURE PROBES ONE AND TWO (SEE TEMPOLD DEFINITION ABOVE).
'    digitaloutput - FEEDS VOLTAGE TO RELAY THAT SWITCHES THE HEATING AND COOLING SYSTEMS.

'DATA FILES:

'    CALIB.DAT - CONTAINS THE SLOPE AND Y-INTERCEPT VALUES FOR THE TEMPERATURE PROBE CALIBRATION EQUATIONS
'    CTRL.DAT - CONTAINS TIME AND TEMPERATURE DATA FOR THE CONTROL PROBES
'    START.DAT - CONTAINS TIME AND DATE DATA FOR CYCLES AND CHANGEOVERS
'    TEST.DAT - CONTAINS TIME AND TEMPERATURE FOR REMAINDER OF PROBES
'    TTLCYCLE.DAT - CONTAINS THE ELAPSED NUMBER OF CYCLES

'THESE LINES INITIALIZE THE VARIABLES, INCLUDING DIMENSIONING ARRAYS:

DIM tempctrl$(4, 500), temp(8), tempstore$(7, 500), dat%(10), ary1%(1000), ary2%(1000), start(1001)   'DIMENSION OF ARRAYS
CLEAR , , 10000

TIMER ON        'STARTS THE TIMER FUNCTION TO CLACULATE ELAPSED TIME TO DETERMINE PHASE RATIOS IN CYCLES

'THESE VALUES ARE USED TO CALCULATE THE RATIO OF HEATING TO COOLING PHASE TIMES:

       status = 0
       elapsed = 0
       hotend = 0
       coolend = 0
```

```
        lowpoint = -16.7  'INITIALIZES THE LOW TEMPERATURE CHANGEOVER POINT
        hipoint = 1.2  'INITIALIZES THE HIGH TEMPERATURE CHANGEOVER POINT


'THESE LINES INITIALIZE THE DATA FILES:

        OPEN "c:\ftfiles\CTRL.DAT" FOR APPEND AS #1
'        OPEN "c:\ftfiles\TEST.DAT" FOR APPEND AS #2   [REMARKED OUT UNTIL THESE PROBES ARE INSTALLED]
        OPEN "c:\ftfiles\START.DAT" FOR APPEND AS #3

        OPEN "c:\ftfiles\TTLCYCLE.DAT" FOR INPUT AS #4
              INPUT #4, ttlcycle
        CLOSE #4


        OPEN "c:\ftfiles\CALIB.DAT" FOR INPUT AS #5
              INPUT #5, mcal1, bcal1
              INPUT #5, mcal2, bcal2
'          INPUT #5, mcal3, bcal3   '[REMARKED OUT UNTIL THESE PROBES ARE INSTALLED]
'          INPUT #5, mcal4, bcal4   '[REMARKED OUT UNTIL THESE PROBES ARE INSTALLED]
'          INPUT #5, mcal5, bcal5   '[REMARKED OUT UNTIL THESE PROBES ARE INSTALLED]
'          INPUT #5, mcal6, bcal6   '[REMARKED OUT UNTIL THESE PROBES ARE INSTALLED]
'          INPUT #5, mcal7, bcal7   '[REMARKED OUT UNTIL THESE PROBES ARE INSTALLED]
'          INPUT #5, mcal8, bcal8   '[REMARKED OUT UNTIL THESE PROBES ARE INSTALLED]
        CLOSE #5
        OPEN "c:\ftfiles\TTLCYCLE.DAT" FOR APPEND AS #4

count = 0                                    'INITIALIZE COUNT

'THE FOLLOWING LINES PROMPT THE OPERATOR TO REQUEST STARTUP OF THE POWER ACTIVATION SEQUENCE:

A:  INPUT "PLEASE ENTER THE NUMBER OF CYCLES DESIRED (36 MAXIMUM): "; nocycles

'THIS LOOP PERFORMS THE VALIDATION OF NOCYCLES INPUT:

        IF nocycles > 36 OR nocycles < 1 OR ABS(INT(nocycles)) <> nocycles THEN
              PRINT "THE NUMBER OF CYCLES MUST BE A POSITIVE INTEGER BETWEEN 1 AND 36.  PLEASE TRY AGAIN."
              GOTO A
        END IF

        INPUT "PLEASE ENTER Y TO START CYCLING: "; power$

'THIS LOOP PERFORMS THE VALIDATION OF POWER$ INPUT:

A1:       IF power$ <> "Y" AND power$ <> "y" THEN
```

```
            PRINT "THAT IS NOT A VALID INPUT.  PLEASE TYPE IN   Y   TO PLACE THE MACHINE ON STANDBY."
            INPUT power$
            GOTO A1
      END IF

'THESE LINES INITIALIZE INTERNAL VARIABLES:

CLS

               GOSUB adconv                       'DETERMINE PROBE TEMPERATURES

      lowtemp = (temp(1) + temp(2)) / 2   'SET THE INITIAL VALUE OF LOWTEMP BY CALCULATING AVERAGE OF CONTROL PROBE TEMPERATURES
      hitemp = 0  'SETS THE INITIAL VALUE OF HITEMP.  A VALUE OF ZERO IS USED BECAUSE THE PROBE SPECIMENS ARE TYPICALLY AT ROOM
                  '  TEMPERATURE (APPROXIMATELY 20°C) AT THE START OF THE FIRST CYCLE.  THE TEMPERATURE IS TOO HIGH TO BE USED
                  '  AS A REFERENCE AS NORMAL OPERATING TEMPERATURES SHOULD NOT GO ABOVE 10°C DURING CYCLING AND THE INITIAL
                  '  VALUE WILL NEVER BE RESET.

C:             GOSUB adconv                       'DETERMINE PROBE TEMPERATURES

      tempold = (temp(1) + temp(2)) / 2   'CALCULATE AVERAGE OF CONTROL PROBE TEMPERATURES


'THESE LINES CHECK FOR INPUT FROM THE KEYBOARD.  IF THE INPUT IS AN S OR s, THE PROGRAMS GOES
'  TO SUBROUTINE BREAKOUT TO CHANGE THE OPERATIONAL MODE (SEE VARIABLE DEFINITIONS FOR STATUS
'  VALUES):


      hold$ = INKEY$
      IF hold$ = "S" OR hold$ = "s" THEN
            GOSUB breakout
            IF status = 2 THEN END
            IF status = 1 THEN GOTO A1
            IF status = 3 THEN GOTO D
      END IF

      phase = 1                                'COOLING PHASE
      GOSUB digitaloutput            'EXECUTES PHASE

'THESE LINES OUTPUT STARTUP TIME AND DATE TO THE DATA FILE:

D:         PRINT #3, "STARTUP AT  : "; DATE$, TIME$
            starttime$ = TIME$
            phasetime$ = TIME$
            toarray = 0
            cycle = 1
D1:          count = 0
```

```
D2:  GOSUB adconv             'ACCESS DIGITAL TO ANALOG CONVERTOR FOR PROBE TEMEPRATURES

'THIS IF LOOP INCREMENTS ELAPSED IF ONE SECOND HAS PASSED SINCE THE LAST INCREMENT OF
'    ELAPSED OR IF MIDNIGHT HAS PASSED:

E:    GOSUB adconv                       'ACCESS A/D CONVERTER FOR TEMPERATURES

       ON TIMER(1) GOSUB phaseratio

       GOSUB daconv                       'ACCESS D/A CONVERTER FOR OUTPUT TO STRIP CHART RECORDER

       IF cycle = nocycles + 1 THEN       'DESIRED ELAPSED CYCLES BEFORE INSPECTION (ASTM C666)
             phase = 0                     'PLACE MACHINE ON SHUTDOWN
             GOSUB digitaloutput       'ACCESS DIGITAL OUTPUTS AND EXECUTE PHASE
             GOTO X
       END IF

' THESE LINES PRINT THE MACHINE CONDITION DATA TO THE SCREEN AND UPDATE AS ADCONV IS ACCESSED:

       CLS
       PRINT "OPERATIONAL MODE:"
       PRINT "THE DATE IS "; DATE$
       PRINT "THE TIME IS "; TIME$
       PRINT
       PRINT "THE CYCLE NUMBER IS "; cycle; " ("; ttlcycle - 1; " TOTAL CYCLES ELAPSED)"
       PRINT "   REQUESTED CYCLES: "; nocycles
       PRINT "  CYCLE INITIATED AT "; starttime$; "."
       IF phase = 1 THEN PRINT "    COOLING PHASE, INITIATED AT "; phasetime$
       IF phase = 2 THEN PRINT "    HEATING PHASE, INITIATED AT "; phasetime$

       IF elapsed <> 0 AND hotend <> 0 AND coolend <> 0 AND start(ttlcycle - 1) <> 0 AND (hotend - start(ttlcycle - 1)) <> 0 THEN
          PRINT USING "THE TIME RATIO OF HEATING TO COOLING IS #.### (0.25 min)."; ABS(hotend - coolend) / (hotend -
start(ttlcycle - 1))
       ELSE PRINT
       END IF

       PRINT USING "THE AVERAGE TEMPERATURE OF THE CONTROL PROBES IS ###.# øC."; (temp(1) + temp(2)) / 2
       PRINT USING "PROBE NUMBER ONE TEMPERATURE IS ###.# øC"; temp(1)
       PRINT USING "PROBE NUMBER TWO TEMPERATURE IS ###.# øC"; temp(2)
       PRINT USING "THE LOWEST AND HIGHEST AVERAGE PROBE TEMPS ARE, RESPECTIVELY: ###.# AND ###.# øC."; lowtemp; hitemp
       PRINT USING "THE LOW AND HIGH CHANGEOVER POINTS ARE, RESPECTIVELY: ###.# AND ###.# øC."; lowpoint; hipoint
       PRINT tempold

'THESE LINES DISPLAY THE OPTION OF BREAKING FROM THE REGULAR PROGRAM TO CHANGE MODES:
```

```
LOCATE 23, 1

        PRINT
        PRINT "PRESS S TO CHANGE MODES AND/OR CHANGEOVER POINTS"
        PRINT "(DO NOT RESET CHANGEOVER POINTS UNTIL AFTER THE FIRST CYCLE)"

'THESE LINES CHECK FOR INPUT FROM THE KEYBOARD.  IF THE INPUT IS AN S OR s, THE PROGRAMS GOES
'  TO SUBROUTINE BREAKOUT TO CHANGE THE OPERATIONAL MODE (SEE VARIABLE DEFINITIONS FOR STATUS
'  VALUES):

        hold$ = INKEY$
        IF hold$ = "S" OR hold$ = "s" THEN
              GOSUB breakout
              IF status = 2 THEN END
              IF status = 1 THEN GOTO A1
              IF status = 3 THEN GOTO D
        END IF

        tempnew = (temp(1) + temp(2)) / 2  'COMPUTES AVERAGE OF CONTROL PROBE TEMPERATURE
        IF tempnew < lowtemp THEN lowtemp = tempnew  'RESETS THE VALUE OF LOWTEMP IF THE CURRENT AVERAGE PROBE TEMPERATURE IS
LOWER
        IF cycle > 1 AND tempnew > hitemp THEN hitemp = tempnew  'RESETS THE VALUE OF HITEMP IF THE CURRENT AVERAGE PROBE
                                                '  TEMPERATURE IS HIGHER AND THE CYCLE IS NOT THE FIRST (THE INITIAL
                                                '  TEMPERATURE IS HIGHER THAN THE NORMAL MAXIMUM CYCLE TEMPERATURE).

'THIS IF LOOP CHECKS THE AVERAGE CONTROL PROBE TEMPERATURE FOR A ONE øC VARIATION FROM THE LAST
'  STORED VALUE:

        IF ABS(tempold - tempnew) >= 1 THEN
              tempold = tempnew 'RESETS TEMPOLD WHEN CURRENT TEMPERATURE CHANGES BY ONE øC
              toarray = 1 'ACTIVATES FUNCTION TO SAVE DATA TO THE ARRAYS FOR LATER DISK STORAGE
              count = count + 1 'INCREMENTS COUNT TO INDICATE HOW MANY DATA POINTS TO SAVE
        END IF

        IF toarray <> 1 THEN GOTO EA  'BYPASSES STATEMENTS THAT SAVE DATA TO ARRAYS

              tempctrl$(2, count) = STR$((FIX((temp(1) + temp(2)) / 2) * 10) / 10)
              tempctrl$(3, count) = STR$((FIX(temp(1) * 10) / 10))
              tempctrl$(4, count) = STR$((FIX(temp(2) * 10) / 10))
              tempctrl$(1, count) = TIME$

              LOCATE 16, 1: FOR I = 1 TO 4: PRINT tempctrl$(I, count); : NEXT I: PRINT

'           tempstore$(1, count) = TIME$                          '[REMARKED OUT UNTIL THESE PROBES ARE INSTALLED]
'           tempstore$(2, count) = STR$((FIX(temp(3) * 10) / 10)) '[REMARKED OUT UNTIL THESE PROBES ARE INSTALLED]
'           tempstore$(3, count) = STR$((FIX(temp(4) * 10) / 10)) '[REMARKED OUT UNTIL THESE PROBES ARE INSTALLED]
```

```
'          tempstore$(4, count) = STR$((FIX(temp(5) * 10) / 10)) '[REMARKED OUT UNTIL THESE PROBES ARE INSTALLED]
'          tempstore$(5, count) = STR$((FIX(temp(6) * 10) / 10)) '[REMARKED OUT UNTIL THESE PROBES ARE INSTALLED]
'          tempstore$(6, count) = STR$((FIX(temp(7) * 10) / 10)) '[REMARKED OUT UNTIL THESE PROBES ARE INSTALLED]
'          tempstore$(7, count) = STR$((FIX(temp(8) * 10) / 10)) '[REMARKED OUT UNTIL THESE PROBES ARE INSTALLED]

             toarray = 0              'REINITIALIZES TOARRAY

'THIS LOOP DETERIMINES WHEN CHANGEOVER OCCURS, EITHER FROM HOT TO COLD CYCLING OR THE REVERSE:

EA:          IF (temp(1) + temp(2)) / 2 <= lowpoint AND phase = 1 THEN      'CHANGEOVER POINT (FROM COOLING PHASE)
             phase = 2                'HEATING PHASE
             GOSUB digitaloutput                'ACCESS DIGITAL OUTPUTS AND EXECUTE PHASE

                    coolend = elapsed       'SETS THE ELAPSED TIME IN SECONDS AT THE END OF THE COOLING PHASE

                    phasetime$ = TIME$       'STORES START OF HEATING PHASE
                    PRINT #3, "HEATING PHASE AT "; TIME$; " ON "; DATE$    'SAVES START OF HEATING PHASE TIME TO DISK

             ELSEIF (temp(1) + temp(2)) / 2 >= hipoint AND phase = 2 THEN       'CHANGEOVER POINT (FROM HEATING PHASE)
             phase = 1                'COOLING PHASE
             GOSUB digitaloutput                'ACCESS DIGITAL OUTPUTS AND EXECUTE PHASE

                    hotend = elapsed       'SETS THE ELAPSED TIME IN SECONDS AT THE END OF THE HEATING PHASE
                    start(ttlcycle) = elapsed       'SETS THE ELAPSED TIME IN SECONDS AT THE END OF THE CYCLE

                    cycle = cycle + 1                       'INCREMENT CYCLE COUNTER
                    ttlcycle = ttlcycle + 1       'INCREMENT TOTAL NUMBER OF CYCLES

                    PRINT #3, "COOLING PHASE AT "; TIME$; " ON "; DATE$   'SAVES START OF COOLING PHASE TIME TO DISK
                    GOSUB TODISK

                    starttime$ = TIME$            'STORE CYCLE START TIME
                    phasetime$ = TIME$            'STORE COOLING PHASE START TIME

       END IF

       IF CYCLES - 1 <> nocycles THEN GOTO D2  'CHECKS TO SEE IF ELAPSED CYCLES IS AT INSPECTION POINT

'THESE PRINT STATEMENTS DISPLAY THE STATUS ON SHUTDOWN FOR INSPECTION AND PRINTS THE DATA TO FILE:

X:  PRINT "NORMAL SHIFT INTO SHUTDOWN MODE."; cycle - 1; " CYCLES COMPLETED."
    PRINT "  AT "; TIME$; " ON "; DATE$
           PRINT #3, USING "NORMAL SHUTDOWN AT ## CYCLES, ON"; cycle - 1;
           PRINT #3, DATE$; ", AT "; TIME$; " ("; ttlcycle; " CYCLES TOTAL)"
           PRINT #4, ttlcycle
       CLOSE ALL
```

```
X1: INPUT "PRESS 1 AND ENTER TO FULLY THAW SPECIMENS, 2 AND ENTER TO CONTINUE WITHOUT THAWING:  ", RETHAW$
       IF RETHAW$ <> "1" AND RETHAW$ <> "2" THEN
         PRINT "THAT IS NOT A VALID OPTION.  PLEASE TRY AGAIN."
         GOTO X1
       END IF

       IF RETHAW$ = "1" THEN GOSUB THAW

Y:  INPUT "PRESS 1 AND ENTER TO CONTINUE CYCLING, 2 AND ENTER TO END"; restart$

'THIS IF LOOP VALIDATES USER INPUT OF RESTART$:

IF restart$ <> "1" AND restart$ <> "2" THEN
         PRINT "THAT IS NOT A VALID OPTION.  PLEASE TRY AGAIN."
         GOTO Y
END IF

'THIS LOOP CONFIRMS THAT THE OPERATOR WISHES TO RESTART CYCLING:

IF restart$ = "1" THEN
         INPUT "YOU HAVE CHOSEN TO CONTINUE CYCLING.  ARE YOU SURE?", choice$
         IF choice$ = "Y" OR choice$ = "y" THEN GOTO A ELSE GOTO Y
END IF

'THIS LOOP CONFIRMS THAT THE OPERATOR WISHES TO END TESTING:

IF restart$ = "2" THEN

          INPUT "YOU HAVE CHOSEN TO END TESTING.  ARE YOU SURE?", choice$

       IF choice$ = "Y" OR choice$ = "y" THEN

           PRINT "TESTING IS CONCLUDED WITH "; cycle - 1; " CYCLES COMPLETED ("; ttlcycle; " TOTAL) AT "; TIME$; " ON "; DATE$; "."

           PRINT #3, USING "SHUTDOWN AT ## CYCLES, ON"; cycle - 1;
           PRINT #3, DATE$; ", AT "; TIME$; " ("; ttlcycle; " CYCLES TOTAL)"
           PRINT #4, ttlcycle
           CLOSE ALL
           phase = 0
           GOSUB digitaloutput
       END

             END IF

       ELSE GOTO Y
```

```
END IF

TIMER OFF

END

'*******************************************************  SUBROUTINES  ****************************************************

'THIS SUBROUTINE ACCESSES THE PCL-711 A/D CONVERTER TO OBTAIN THE TEMPERATURE DATA TO CONTROL  THE
'   MACHINE CYCLING:

adconv:

'THESE STATEMENTS INITIALIZE THE tempsumx VARIABLES USED TO STABILIZE THE TEMPERATURE DATA:

       tempsum1 = 0: tempsum2 = 0
' : tempsum3 = 0: tempsum4 = 0: tempsum5 = 0: tempsum6 = 0: tempsum7 = 0: tempsum8 = 0[REMARKED OUT UNTIL THESE PROBES
'   ARE INSTALLED]


       ER% = 0                        'SETS THE PCL-711S DRIVER ERROR RETURN CODE FUNCTION
       PORT% = &H220                  'SETS THE HARDWARE ADRESS FOR THE PCL_711S I/O BOARD
       dat%(0) = PORT%                'ASSIGNS THE PORT TO A DRIVER VARIABLE
       fun% = 0                            'FUNCTION 0, INITIALIZE DRIVER
       CALL PCL711(fun%, SEG dat%(0), SEG ary1%(0), SEG ary2%(0), ER%)        'CALLS THE PCL-711S DRIVER

       start% = 0: dat%(0) = start%  'SETS THE DRIVER TO START AT THE FIRST CHANNEL FOR THE INPUT RANGE
       stp% = 7: dat%(1) = stp%      'SETS THE DRIVER TO STOP AT THE LAST CHANNEL FOR THE INPUT RANGE
       fun% = 1                            'PCL-711S FUNCTION 1, SET INPUT CHANNEL RANGE
       CALL PCL711(fun%, SEG dat%(0), SEG ary1%(0), SEG ary2%(0), ER%)        'CALLS THE PCL-711S DRIVER

       fun% = 3                            'FUNCTION 3, PERFORM SINGLE A/D CONVERSION

'THESE NESTED LOOPS ACCESS THE DRIVER FUNCTION AND CALCULATE THE PROBE'S TEMPERATURE, BASED ON THE CALIBRATION
'   EQUATIONS:

FOR J = 1 TO 1000
   FOR I = 1 TO 8
       CALL PCL711(fun%, SEG dat%(0), SEG ary1%(0), SEG ary2%(0), ER%)        'CALLS THE PCL-711S DRIVER
       IF I = 1 THEN                                                        'TEMP. OF FIRST PROBE (CONTROL SPECIMEN, PROBE #1)
             temp1 = mcal1 * (.002445 * dat%(0)) + bcal1
       END IF

       IF I = 2 THEN                                                        'TEMP. OF SECOND PROBE (CONTROL SPECIMEN, PROBE #2))
             temp2 = mcal2 * (.002445 * dat%(0)) + bcal2
```

```
       END IF

'    [REMARKED OUT UNTIL THESE PROBES ARE INSTALLED]
'
'          IF I = 3 THEN temp3 = mcal3 * (.002445 * DAT%(0)) + BCAL3'TEMP. OF TEST TANK PROBE ONE (PROBE #3)
'          IF I = 4 THEN temp4 = mcal4 * (.002445 * DAT%(0)) + BCAL4'TEMP. OF TEST TANK PROBE TWO (PROBE #4)
'          IF I = 5 THEN temp5 = mcal5 * (.002445 * DAT%(0)) + BCAL5'TEMP. OF TEST TANK PROBE THREE (PROBE #5)
'          IF I = 6 THEN temp6 = mcal6 * (.002445 * DAT%(0)) + BCAL6'TEMP. OF TEST TANK PROBE FOUR (PROBE #6)
'          IF I = 7 THEN temp7 = mcal7 * (.002445 * DAT%(0)) + BCAL7'TEMP. OF HOT HOLDING TANK PROBE (PROBE #7)
'          IF I = 8 THEN temp8 = mcal8 * (.002445 * DAT%(0)) + BCAL8'TEMP. OF COLD HOLDING TANK PROBE (PROBE #8)
   NEXT I

'THESE STATEMENTS SUM THE CALCULATED PROBE TEMPERATUES:

 tempsum1 = temp1 + tempsum1
 tempsum2 = temp2 + tempsum2

'[REMARKED OUT UNTIL THESE PROBES ARE INSTALLED]
'
' tempsum3 = TEMP3 + tempsum3
 'tempsum4 = TEMP4 + tempsum4
 'tempsum5 = TEMP5 + tempsum5
 'tempsum6 = TEMP6 + tempsum6
 'tempsum7 = TEMP7 + tempsum7
 'tempsum8 = TEMP8 + tempsum8

NEXT J

'THESE STATEMENTS AVERAGE THE SUMMED PROBE TEMPERATURES TO RETURN VALUES TO THE PROGRAM:

       temp(1) = tempsum1 / 1100
       temp(2) = tempsum2 / 1100

'[REMARKED OUT UNTIL THESE PROBES ARE INSTALLED]
'
'    temp(3) = tempsum3 / 1100
'    temp(4) = tempsum4 / 1100
'    temp(5) = tempsum5 / 1100
'    temp(6) = tempsum6 / 1100
'    temp(7) = tempsum7 / 1100
'    temp(8) = tempsum8 / 1100

RETURN


' THIS SUBROUTINE ALLOWS THE USER TO BREAK INTO THE PROGRAM TO INITIATE EMERGENCY MEASURES:
```

```
breakout:

'THESE LINES STORE THE CURRENT PHASE AND SET THE MACHINE TO STANDBY AS A SAFETY  MEASURE:

        phasetemp = phase
        phase = 0
        GOSUB digitaloutput

'THESE STATEMENTS PROMPT THE OPERATOR TO ENTER THE MODE DESIRED:

E1:  CLS

        INPUT "DO YOU WISH TO ALTER A CHANGEOVER POINT (Y OR N)"; change$

'THIS IF LOOP VALIDATES THE VALUE OF CHANGE$:

        IF change$ <> "Y" AND change$ <> "y" AND change$ <> "N" AND change$ <> "n" THEN
              PRINT "THAT IS NOT AN OPTION.  PLEASE TRY AGAIN."
              GOTO E1
        END IF

        IF change$ = "N" OR change$ = "n" THEN GOTO F

' THE FOLLOWING LINES ALLOW THE OPERATOR TO CHANGE THE HIGH CHANGEOVER POINT AND PROVIDE INFORMATION
'   TO MAKE A PROPER SELECTION:

E2: CLS

        PRINT "THE HIGHEST TEMPERATURE TO BE REACHED IS 4.4 øC.  THE HIGH CHANGEOVER POINT"
        PRINT "SHOULD BE APPROXIMATELY THE DIFFERENCE BETWEEN THE HIGHEST ACTUAL TEMPERATURE"
        PRINT "AND THE CURRENT CHANGEOVER POINT (SHOWN WITH THE OPTION TO CHANGE THE"
        PRINT "CHANGEOVER POINT).  SOME ADJUSTMENT MAY BE REQUIRED."
        PRINT
        PRINT "WHAT IS THE NEW HIGH CHANGEOVER POINT (ACCEPTABLE RANGE IS -4 TO 4.4)?"
        PRINT USING "(THE CURRENT IS ###.# øC)"; hipoint
        PRINT USING "(THE HIGHEST ACTUAL TEMPERATURE REACHED IS ###.# øC)"; hitemp
        INPUT hipointnew

        IF hipointnew > 4.4 OR hipointnew < -4 THEN
              PRINT "THAT IS NOT AN OPTION.  PLEASE TRY AGAIN."
              GOTO E2
        END IF

'THIS LOOP CONFIRMS THE OPERATOR'S CHOICE OF A NEW HIGH CHANGEOVER POINT"
```

```
E3: CLS

       PRINT USING "YOU HAVE CHOSEN ###.# øC AS THE NEW HIGH CHANGEOVER POINT."; hipointnew
       INPUT "ARE YOU SURE (Y OR N)? "; high$

'THIS IF LOOP VALIDATES THE VALUE OF HIGH$:

       IF high$ <> "Y" AND high$ <> "y" AND high$ <> "N" AND high$ <> "n" THEN
             PRINT "THAT IS NOT AN OPTION.  PLEASE TRY AGAIN."
             GOTO E3
       END IF

       IF high$ = "N" OR high$ = "n" THEN
             GOTO E1
       ELSE
             hipoint = hipointnew
             hitemp = hipoint
       END IF

' THE FOLLOWING LINES ALLOW THE OPERATOR TO CHANGE THE LOW CHANGEOVER POINT AND PROVIDE INFORMATION
'   TO MAKE A PROPER SELECTION:

E4: CLS

       PRINT "THE LOWEST TEMPERATURE TO BE REACHED IS -17.8 øC.  THE LOW CHANGEOVER POINT"
       PRINT "SHOULD BE APPROXIMATELY THE DIFFERENCE BETWEEN THE LOWEST ACTUAL TEMPERATURE"
       PRINT "AND THE CURRENT CHANGEOVER POINT (SHOWN WITH THE OPTION TO CHANGE THE"
       PRINT "CHANGEOVER POINT).  SOME ADJUSTMENT MAY BE REQUIRED."
       PRINT
       PRINT "WHAT IS THE NEW LOW CHANGEOVER POINT (ACCEPTABLE RANGE IS -14.8 TO -17.8)?"
       PRINT USING "(THE CURRENT IS ###.# øC)"; lowpoint
       PRINT USING "(THE LOWEST ACTUAL TEMPERATURE REACHED IS ###.# øC)"; lowtemp
       INPUT lowpointnew

       IF lowpointnew > -14.8 OR lowpointnew < -17.8 THEN
             PRINT "THAT IS NOT AN OPTION.  PLEASE TRY AGAIN."
             GOTO E4
       END IF

E5: CLS

       PRINT USING "YOU HAVE CHOSEN ###.# øC AS THE NEW HIGH CHANGEOVER POINT."; lowpointnew
       INPUT "ARE YOU SURE (Y OR N)? "; low$

'THIS IF LOOP VALIDATES THE VALUE OF LOW$:
```

```
        IF low$ <> "Y" AND low$ <> "y" AND low$ <> "N" AND low$ <> "n" THEN
              PRINT "THAT IS NOT AN OPTION.  PLEASE TRY AGAIN."
              GOTO E5
        END IF

        IF low$ = "N" OR low$ = "n" THEN
              GOTO E1
        ELSE
              lowpoint = lowpointnew
        END IF

        phase = phasetemp    'RESTORES PHASE TO CONDITION BEFORE INTERRUPTION
        GOSUB digitaloutput
        RETURN      'RETURNS TO THE MAIN PROGRAM

F:  CLS
          PRINT "ENTER Y IF YOU WANT TO STOP THE MACHINE, N TO RETURN TO THE MAIN PROGRAM"
              INPUT t$

'THIS IF LOOP VALIDATES THE VALUE OF t$:

        IF t$ <> "Y" AND t$ <> "y" AND t$ <> "N" AND t$ <> "n" THEN
              PRINT "THAT IS NOT AN OPTION.  PLEASE TRY AGAIN."
              GOTO F
        END IF

'THIS LOOPS RETURNS TO THE MAIN PROGRAM, AT THE PHASE AS WHEN LEFT:

        IF t$ = "N" OR t$ = "n" THEN
              phase = phasetemp    'RESTORES PHASE TO CONDITION BEFORE INTERRUPTION
              GOSUB digitaloutput
              RETURN      'RETURNS TO THE MAIN PROGRAM
        END IF

'THESE STATEMENTS SHOW THE OPERATOR THE MODE SELECTED:

CLS
   PRINT "YOU HAVE CHOSEN TO SHUT DOWN THE MACHINE."

'THESES STATEMENTS CONFIRM THE OPERATOR'S CHOICE:

F1:      INPUT "ARE YOU SURE (ENTER Y FOR YES, N FOR NO):"; inp$

'THIS IF LOOP VALIDATES inp$:

        IF inp$ <> "Y" AND inp$ <> "y" AND inp$ <> "N" AND inp$ <> "n" THEN
```

```
            PRINT "THAT IS NOT A VALID INPUT. PLEASE TRY AGAIN."
            GOTO F1:
      END IF

'THIS LOOPS RETURNS TO THE MAIN PROGRAM, AT THE PHASE AS WHEN LEFT:

      IF inp$ = "N" OR inp$ = "n" THEN
            phase = phasetemp    'RESTORES PHASE TO CONDITION BEFORE INTERRUPTION
            GOSUB digitaloutput
            RETURN      'RETURNS TO THE MAIN PROGRAM
      END IF

'THE FOLLOWING LINES EXECUTE MACHINE SHUTDOWN:

      phase = 0           'ALL POWER (SERVICE, SOLENOIDS AND PUMPS) OFF
      GOSUB digitaloutput       'EXECUTE PHASE
      END

      hold$ = ""               'RESETS HOLD$

RETURN

'THIS SUBROUTINE LINES ACCESS THE PCL-711 D/A CONVERTER TO FEED A VOLTAGE TO THE STRIP CHART RECORDER:

daconv:

      ER% = 0                        'SETS THE PCL-711S DRIVER ERROR RETURN CODE FUNCTION
      PORT% = &H220                  'SETS THE HARDWARE ADRESS FOR THE PCL_711S I/O BOARD
      dat%(0) = PORT%                'ASSIGNS THE PORT TO A DRIVER VARIABLE
      fun% = 0                            'FUNCTION 0, INITIALIZE DRIVER
      CALL PCL711(fun%, SEG dat%(0), SEG ary1%(0), SEG ary2%(0), ER%)        'CALLS THE PCL-711S DRIVER

      dat%(0) = 1                         'SETS THE D/A CHANNEL 1
      dat%(1) = (1.3705 * tempold + 33.6)'VOLTAGE SENT TO STRIP CHART RECORDER
      fun% = 15                           'FUNCTION 15, WRITE DATA TO D/A CHANNEL
      CALL PCL711(fun%, SEG dat%(0), SEG ary1%(0), SEG ary2%(0), ER%)        'CALLS THE PCL-711S DRIVER

RETURN

'********  WRITE DIGITAL OUTPUT USING FUNC 21 ********

digitaloutput:
      IF phase = 0 THEN dat = 0          'SHUTDOWN (0000000000)
      IF phase = 1 THEN dat = 271          'MAIN POWER, COOLING SYSTEM, FAN AND STRIP CHART RECORDER ON (100001111)
      IF phase = 2 THEN dat = 15     'MAIN POWER, HEATING SYSTEM, FAN AND STRIP CHART RECORDER ON (0000001111)
```

```
            fun% = 21                'FUNCTION 21, WRITE OUTPUT TO DIGITAL CHANNELS
                  dat%(1) = dat / 256          'DIGITAL EQUIVALENT OF DECIMAL DATA (CHANNELS 1-8)
                  dat%(0) = dat MOD 256  'DIGITAL EQUIVALENT OF DECIMAL DATA (CHANNELS 9-16)
                  CALL PCL711(fun%, SEG dat%(0), SEG ary1%(0), SEG ary2%(0), ER%)        'CALLS THE PCL-711S DRIVER

RETURN

'THIS SUBROUTINE INCREMENTS ELAPSED WHEN CALLED BY THE ON TIMER STATEMENT:

phaseratio:

       elapsed = elapsed + 1

RETURN

'THIS SUBROUTINE THAWS THE SPECIMENS PRIOR TO INSPECTION:

THAW:

       phase = 2              'HEATING PHASE
       GOSUB digitaloutput            'EXECUTE PHASE

G:   GOSUB adconv                        'ACCESS A/D CONVERTER FOR TEMPERATURES

       IF (temp(1) + temp(2)) / 2 >= 21.1 THEN   'SPECIMENS FULLY THAWED (INCLUDING ICE CAP)
            phase = 0                'STANDBY
            GOSUB digitaloutput                'EXECUTE PHASE
            RETURN
       END IF

       GOSUB adconv                        'DETERMINE PROBE TEMPERATURES

       thawtemp = ((temp(1) + temp(2)) / 2)  'CALCULATE AVERAGE OF CONTROL PROBE TEMPERATURES
                                                 'PRINT TO SCREEN

'THESE LINES DISPLAY THE OPTION OF BREAKING FROM THE REGULAR PROGRAM TO CHANGE MODES:

LOCATE 20, 1

       PRINT USING "THE AVERAGE OF THE CONTROL PROBE TEMEPRATURES IS ###.# øC"; thawtemp
       PRINT "PRESS S TO CHANGE MODES AND/OR CHANGEOVER POINTS"
       PRINT "(DO NOT RESET CHANGEOVER POINTS UNTIL AFTER THE FIRST CYCLE)"

'THESE LINES CHECK FOR INPUT FROM THE KEYBOARD.  IF THE INPUT IS AN S OR s, THE PROGRAMS GOES
'  TO SUBROUTINE BREAKOUT TO CHANGE THE OPERATIONAL MODE (SEE VARIABLE DEFINITIONS FOR STATUS
'  VALUES):
```

```
        hold$ = INKEY$
        IF hold$ = "S" OR hold$ = "s" THEN
              GOSUB breakout
              IF status = 2 THEN END
              IF status = 1 THEN GOTO A1
              IF status = 3 THEN GOTO D
        END IF

        GOTO G:

RETURN



'THIS SUBROUTINE SAVES THE TEST DATA TO DISK:

TODISK:

'THIS LOOP OUTPUTS TEMPERATURE VALUES TO THE DATA FILES AT THE CYCLE INCREMENTS:

              PRINT #1, ttlcycle  'STORES THE NUMBER OF EFFECTIVE CYCLES TO CTRL.DAT

        FOR N = 1 TO count

              PRINT #1, tempctrl$(2, N); "  "; tempctrl$(1, N); "  "; tempctrl$(3, N); " "; tempctrl$(4, N)'SAVE TO CTRL.DAT

'THE FOLLOWING STATEMENTS SAVE DATA TO TEST.DAT:

'THE FOLLOWING 3 LINES ARE REMARKED OUT UNTIL THE SIX ADDITIONAL PROBES ARE INSTALLED:

'          PRINT #2, tempstore$(1, N); "    "; tempstore$(2, N); "  "; tempstore$(3, N); "  ";
'          PRINT #2, tempstore$(4, N); "  "; tempstore$(5, N); "  ";
'          PRINT #2, tempstore$(6, N); "  "; tempstore$(7, N)

        NEXT N

              PRINT #3, "CYCLE NO.: "; cycle; " STARTED ON "; DATE$; " AT "; TIME$; cycle'SAVE TO START.DAT
              IF elapsed <> 0 AND hotend <> 0 AND coolend <> 0 AND start(ttlcycle - 1) <> 0 AND (hotend - start(ttlcycle - 1)) <>
0 THEN
                     PRINT #3, "THE TIME RATIO OF HEATING TO COOLING IS #.### (0.25 min)."; ABS(hotend - coolend) / (hotend -
start(ttlcycle - 1))
              END IF
              count = 0                                    'REINITIALIZE COUNT

RETURN
```

Appendix F

Temperature Data: Probe Calibration and Machine Operation

Table F1 and Figure F1 show the calibration values for two typical probes (although not the ones used in the machine). See Appendix D for more details on the procedure. Running the values through a regression analysis gave a high correlation (>99%) using a first order equation. Several runs gave comparable results.

PROBE #1 TEMP = -10.2 * (PROBE #1 VOLTAGE) + 23.6
PROBE #2 TEMP = -9.5 * (PROBE #2 VOLTAGE) +19.7

where the coefficient is in °C/volts and the intercept is in °C.

Table F2 and Figure F2 show the typical temperature values recorded by the computer during cycling. The first cycle is the initial startup and as such is somewhat unstable in terms of the temperature variations. After the cooling phase, the variations decrease to within the tolerances specified in ASTM C 666. The average of the probe values, each individual probe value and the difference between the probes are shown.

MEASURED TEMP (°C)	MEASURED VOLTAGE PROBE#1 (volts)	CALC. TEMP. PROBE#1 (°C)	MEASURED VOLTAGE PROBE#2 (volts)	CALC. TEMP. PROBE#1 (°C)
-20.6	4.32	-20.4	4.26	-20.6
-20.0	4.27	-19.9	4.20	-20.0
-19.4	4.22	-19.4	4.13	-19.4
-18.9	4.18	-18.9	4.08	-18.9
-18.3	4.12	-18.4	4.04	-18.5
-17.8	4.08	-18.0	3.97	-17.9
-17.2	4.00	-17.2	3.87	-16.9
-16.7	3.95	-16.6	3.81	-16.4
-16.1	3.91	-16.3	3.79	-16.1
-15.6	3.84	-15.5	3.72	-15.5
-15.0	3.78	-14.9	3.69	-15.2
-14.4	3.74	-14.5	3.61	-14.5
-13.9	3.70	-14.1	3.57	-14.1
-13.3	3.65	-13.6	3.51	-13.5
-12.8	3.58	-12.8	3.44	-12.8
-12.2	3.51	-12.1	3.37	-12.2
-11.7	3.46	-11.6	3.31	-11.6
-11.1	3.39	-10.9	3.24	-10.9
-10.6	3.34	-10.4	3.18	-10.4
-10.0	3.29	-9.9	3.13	-9.9
-9.4	3.24	-9.4	3.08	-9.5
-8.9	3.19	-8.9	3.02	-8.9
-8.3	3.14	-8.4	2.96	-8.4
-7.8	3.09	-7.9	2.91	-7.9
-7.2	3.05	-7.4	2.86	-7.4
-6.7	2.95	-6.4	2.76	-6.5
-6.9	2.98	-6.8	2.79	-6.8
-5.7	2.85	-5.4	2.66	-5.5
-5.0	2.78	-4.7	2.59	-4.8
-4.2	2.71	-4.0	2.51	-4.1
-3.7	2.65	-3.4	2.46	-3.6
-2.7	2.56	-2.5	2.35	-2.6
-2.0	2.50	-1.9	2.28	-1.9
-1.1	2.41	-1.0	2.19	-1.1
-0.6	2.36	-0.5	2.13	-0.5
0.1	2.31	0.1	2.07	0.0
0.8	2.24	0.8	2.00	0.7
1.4	2.17	1.5	1.93	1.3
1.9	2.13	1.9	1.91	1.5
2.7	2.05	2.8	1.80	2.6
3.3	2.00	3.2	1.75	3.1
4.0	1.93	3.9	1.67	3.8
4.8	1.85	4.7	1.58	4.6
5.4	1.80	5.3	1.52	5.2
6.0	1.74	5.8	1.46	5.7
6.6	1.68	6.5	1.41	6.3
7.0	1.65	6.8	1.35	6.8

Table F1 – Probe Calibration Data

Time (24h)	Average Of Probe Temps (°C)	Probe One Temp (°C)	Probe Two Temp (°C)	Probe Difference (°C)
17:45:43	2	1.9	3.6	1.7
17:52:56	1	1.7	1.9	0.2
17:57:21	0	0.4	1.2	0.8
18:00:53	0	-1	0.6	1.6
18:05:14	-1	-2.2	-0.1	2.1
18:09:52	-2	-3.2	-1.1	2.1
18:14:41	-3	-4.2	-2.1	2.1
18:19:02	-4	-5.2	-3.1	2.1
18:23:13	-5	-6.3	-4	2.3
18:27:42	-6	-7.3	-5	2.3
18:32:19	-7	-8.3	-6	2.3
18:37:02	-8	-9.4	-6.9	2.5
18:41:57	-9	-10.4	-7.9	2.5
18:46:57	-10	-11.4	-8.9	2.5
18:52:12	-11	-12.4	-9.9	2.5
18:57:37	-12	-13.4	-10.9	2.5
19:03:13	-13	-14.4	-11.9	2.5
19:08:58	-14	-15.4	-13	2.4
19:14:58	-15	-16.3	-14	2.3
19:21:04	-16	-17.3	-15.1	2.2
19:34:04	-15	-15.5	-14.8	0.7
19:36:01	-14	-14.4	-14	0.4
19:37:52	-13	-13.2	-13.1	0.1
19:39:45	-12	-12.2	-12.1	0.1
19:41:39	-11	-11.1	-11.2	-0.1
19:43:38	-10	-10.1	-10.2	-0.1
19:45:38	-9	-9	-9.2	-0.2
19:47:38	-8	-8	-8.2	-0.2
19:49:40	-7	-7	-7.3	-0.3
19:51:41	-6	-5.9	-6.4	-0.5
19:53:41	-5	-4.8	-5.5	-0.7
19:55:40	-4	-3.6	-4.6	-1
19:57:42	-3	-2.5	-3.7	-1.2
19:59:47	-2	-1.5	-2.7	-1.2
20:02:03	-1	-0.5	-1.7	-1.2
20:04:36	0	0.2	-0.5	-0.7
20:07:39	0	0.8	0.8	0
20:11:32	1	1.3	2.3	1
20:17:38	2	2.3	3.3	1
20:19:17	3	4.2	3.4	-0.8

Table F2 – Cycle Time vs. Temperature Data (One Cycle)

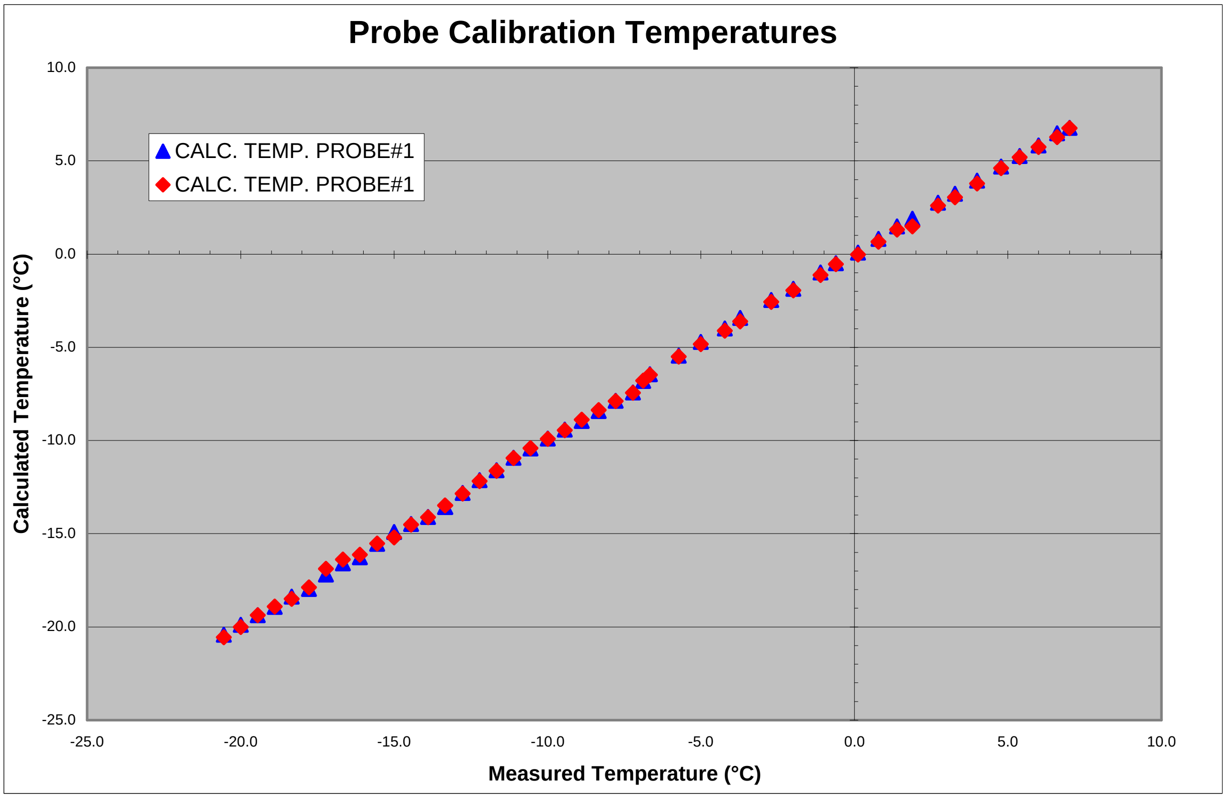

Figure F1 – Probe Calibration Curves

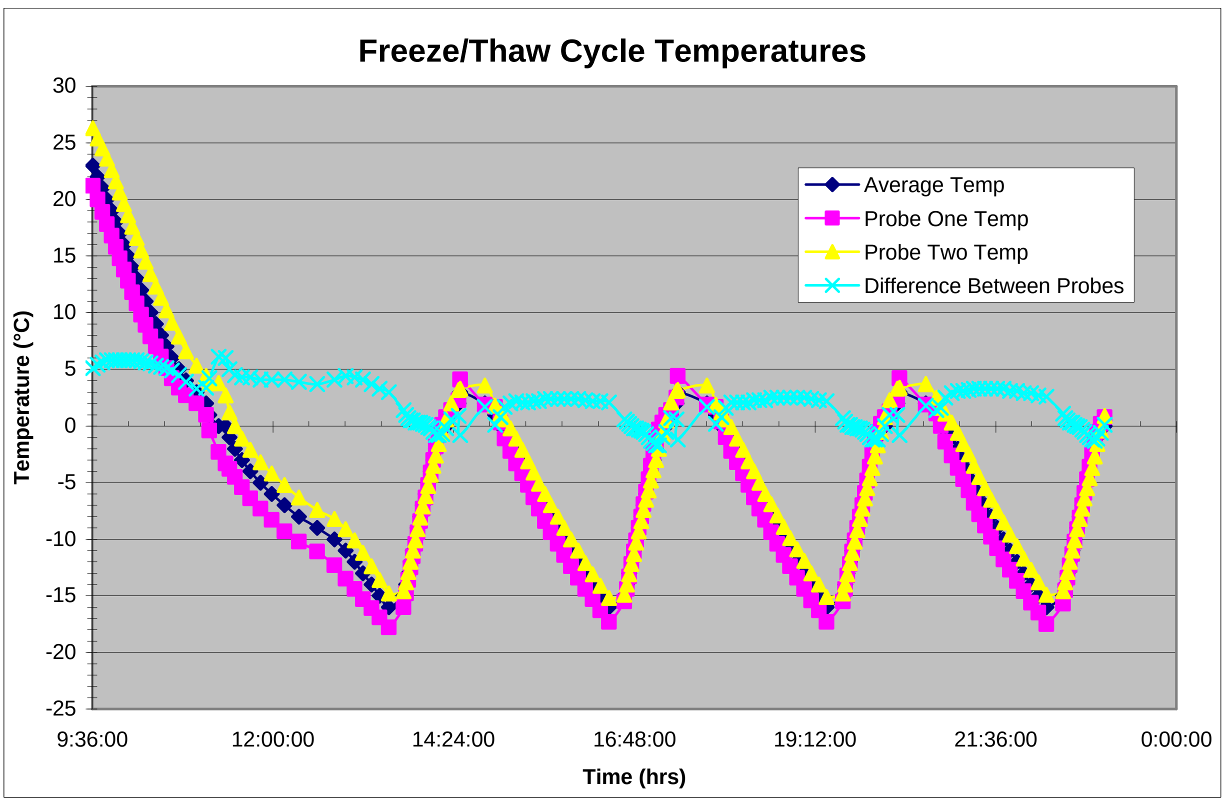

Figure F2 – Freeze/Thaw Machine Temperature Cycling

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APPENDIX G

Contents of Supplied CD-ROM Disc

WINSTART.EXE – Program to create bootable diskette (Windows 98 Startup Disk) for setup of a new system. The disk contains FDISK.EXE to partition the hard drive and creates a RAM disk to that contains the FORMAT.EXE program. It also loads standard DOS CD-ROM drivers. WINSTART98.EXE requires Windows on a machine where the 3.5" floppy drive is designated as "A". There are also instructions on how to partition and format a hard drive, as Acrobat PDF, Word DOC and text files (HD_Setup.txt). Note that any machine used to run the freeze/thaw machine should be dedicated to the task.

DC – This folder contains a menu structure program called Disk Commander to facilitate navigation through the tree structure of DOS. The entire folder can simply be copied to the hard drive.

Dickson – The software to download data from the dataloggers and a schematic to make a new interface cable if needed. This is a Windows program.

FTFILES – This folder contains the QuickBasic software and the program to operate the freeze/thaw machine. Copy the folder to the hard drive. Then type "FT" (for the batch file) at the command prompt within the folder and the program will load. QuickBasic runs in the DOS environment.

PCL711 – This folder contains the drivers and test files for the PCL-711b I/O card that allows the computer to interface with the freeze/thaw machine. It also contains the manual for the card and the PCLD-786 SSR Relay Board as PDF files, as well as a test program for the PCL711b. The Windows drivers are also included, but are not supported by the operational program. Note the files needed to run the program are already in the FTFILES folder and are called by the FT.BAT batch file.

Acrobat505.EXE – This file installs Adobe Acrobat 5.05 in Windows to allow access to the PDF files.

Manual and Related Files - This folder contains the manual as both Acrobat PDF and Word DOC files (if editing is required). The file for the schematics are provided in CorelDraw 10 CDR format (the program used to create it) and as WMF files.

Note : The CD-ROM is bootable for systems that support starting from the CD. It also contains FDISK.EXE, FORMAT.COM and SCANDISK.EXE (for checking the condition of the hard drive, if needed).

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APPENDIX H

Original Operations Manual

Logan Freeze-Thaw Mfg. Co.

CONCRETE TESTING EQUIPMENT

St. George, Utah 84770

The principle of operation of the freeze-thaw machine is to place the concrete specimen in a stainless container with the minimum amount of water (1/8 inch) on all sides and to place the container on a freezing plate that has a felt pad saturated with water for better conductivity between the stainless steel container and the freezing plate. These stainless steel containers are placed side be side with heaters inserted between the containers and stainless steel clips holding the heaters between the stainless steel containers The two metal strips are positioned between the heaters and the freezer plate to support the heaters and hold them from resting directly on the freezer plate. The 1/8 inch brass rods are to keep the specimen off the bottom of the container. The amount of water on top should not exceed 1/4 inch. Each container should have approximately the same amount of water. Keep it minimum.

The cycle starts by lowering the temperature of the freezing plate until zero degree Fahrenheit is reached. A slightly longer container is used to carry a pilot specimen which has the control bulb of the cycle control and the control bulb of the recording thermometer inserted from opposite ends and sealed. Some materials such as hard rubber or plastic may be used on the ends in the pilot specimen to eliminate water from the ends of the container so that freezing temperatures will not cause the ends to bulge out and cause the container to leak. When zero degrees Fahrenheit is reached the heating cycle starts by the heating relay closing the contact that furnishes

Note: Some components as listed here have been replaced with the computer interface components.

electricity to the strip heaters and turning off the refrigeration compressor. 115 volts is supplied to the strip heaters although they are marked 240 volts . This gives a heat output of approximately 125 watts per heater which is sufficient to warm the specimen in the required time and yet not increase the temperature difference between specimen and heating medium beyond 50 degree temperature difference. You will note that two of the heaters have stainless sheaths. These are to be used on the very end specimens since only one side is used to absorb the heat and does not require as much heat.

You will note on the cycle control that both cut-in and cut-out points can be manually adjusted to suit your particular need and can be adjusted to any number of temperatures that you may require.

The fan switch controls a fan that circulates the air under the plate and over the top of the specimens to help maintain a more even temperature in the cabinet and may be turned off with out affecting he actual test, but it does shorten the cycle a few minutes,

The heat limit thermostat is merely a safety device to shut off the heat in the cabinet should some malfunction occur to cause the heaters to stay on. It is normally set at 85 degree Fahrenheit which is more than ample to get the temperature of the specimens to 40 degrees Fahrenheit. However, it is easily adjusted to suit your needs.

To start the machine in operation, load the containers with the desired numbers of specimens and cover with water and turn heater switch, refrigeration switch, fan switch and master switch to "ON" position.

When you desire to take a specimen out, turn the refrigeration switch to the "OFF" position during the thaw cycle so that it will not come back on and freeze up again. The heater switch may be turned off if you desire a very slow thaw cycle.

The whole machine has been designed to be as flexible as possible to meet your individual requirements and still meet the requirements of the industry.

MAINTENANCE

The maintenance of the machine requires that the condenser (radiator) of the refrigeration unit be kept clean and the chart on the recording thermometer be changed regularly. The water on top of the specimens in the containers should be checked to see that they are covered up to 1/4 inch. Any excess water will drain out the bottom of the cabinet through a drain provided in the corner.

The refrigeration unit is a standard Copeland unit, 3/4 hp., 115 volt, with Freon 502 refrigerant. A crankcase regulator is installed in the suction line and set at 20 pounds maximum back pressure to keep the compressor from overloading on the initial pull-down. All parts can be ordered directly from us be description.

Should slow or no freezing be encountered, look into the liquid sight glass on the small refrigerant lines. If a stream of bubbles appears, have a qualified refrigeration man check for refrigerant leaks and recharge with Freon 502.

The motor compressor is covered by a Copeland factory five year warranty.

Be sure that the felt pad under the containers is fully wet with water before starting a test.

Note: The refrigeration system now uses R408A instead of R502, as R502 is no longer available.

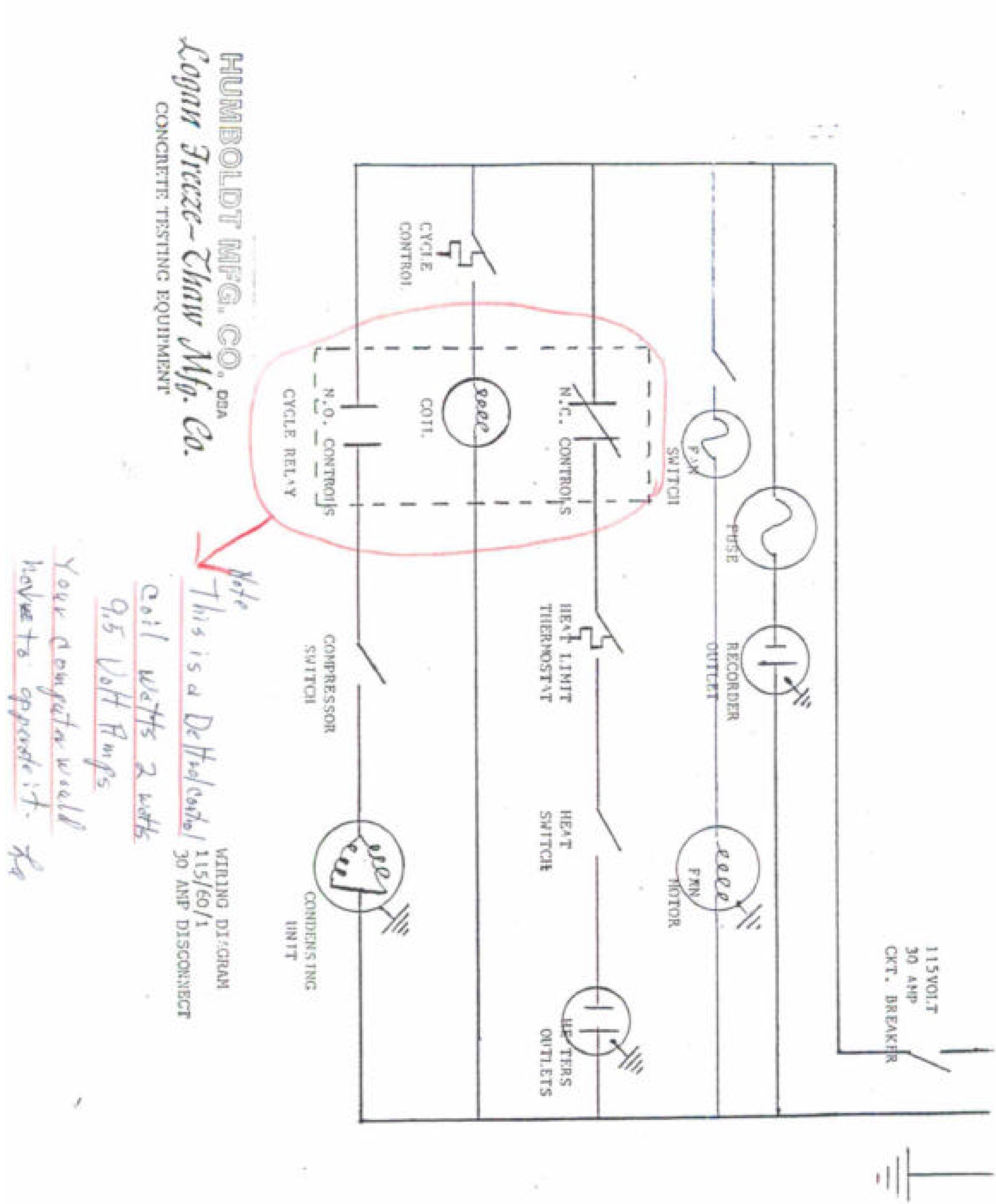

Figure H1 – Original Control System Schematic (unmodified)

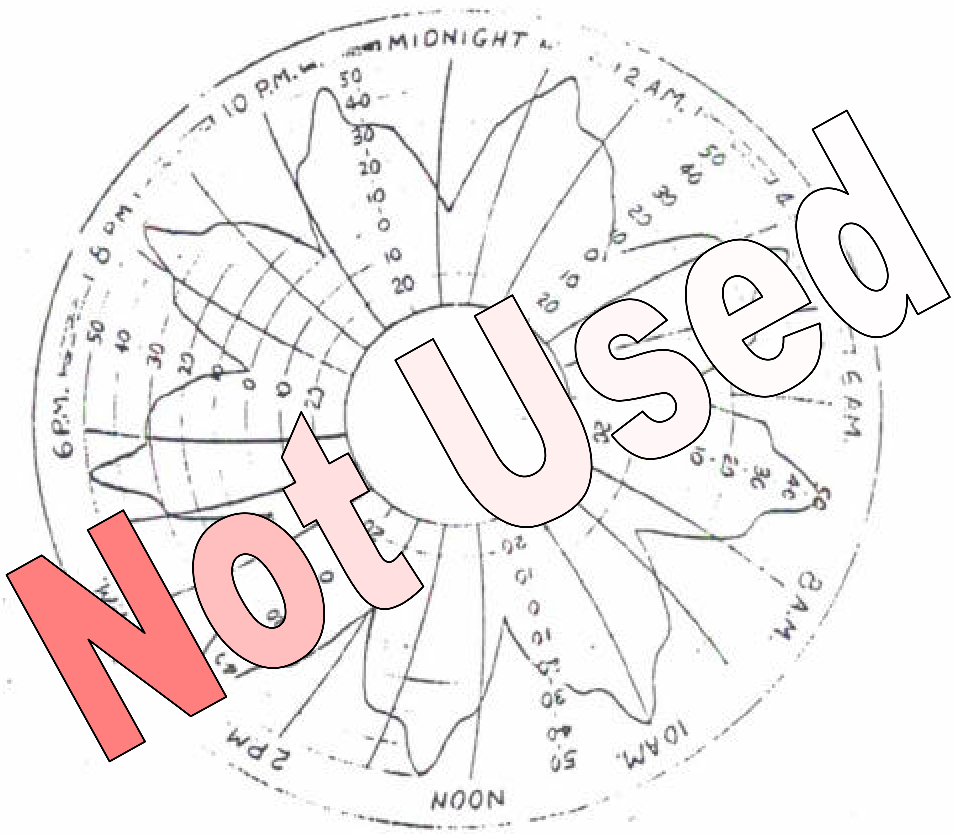

Figure 4. Typical graph of the recording thermometer

Figure H2 – Sample Chart Paper Recording of Cycle Temperatures (not used)

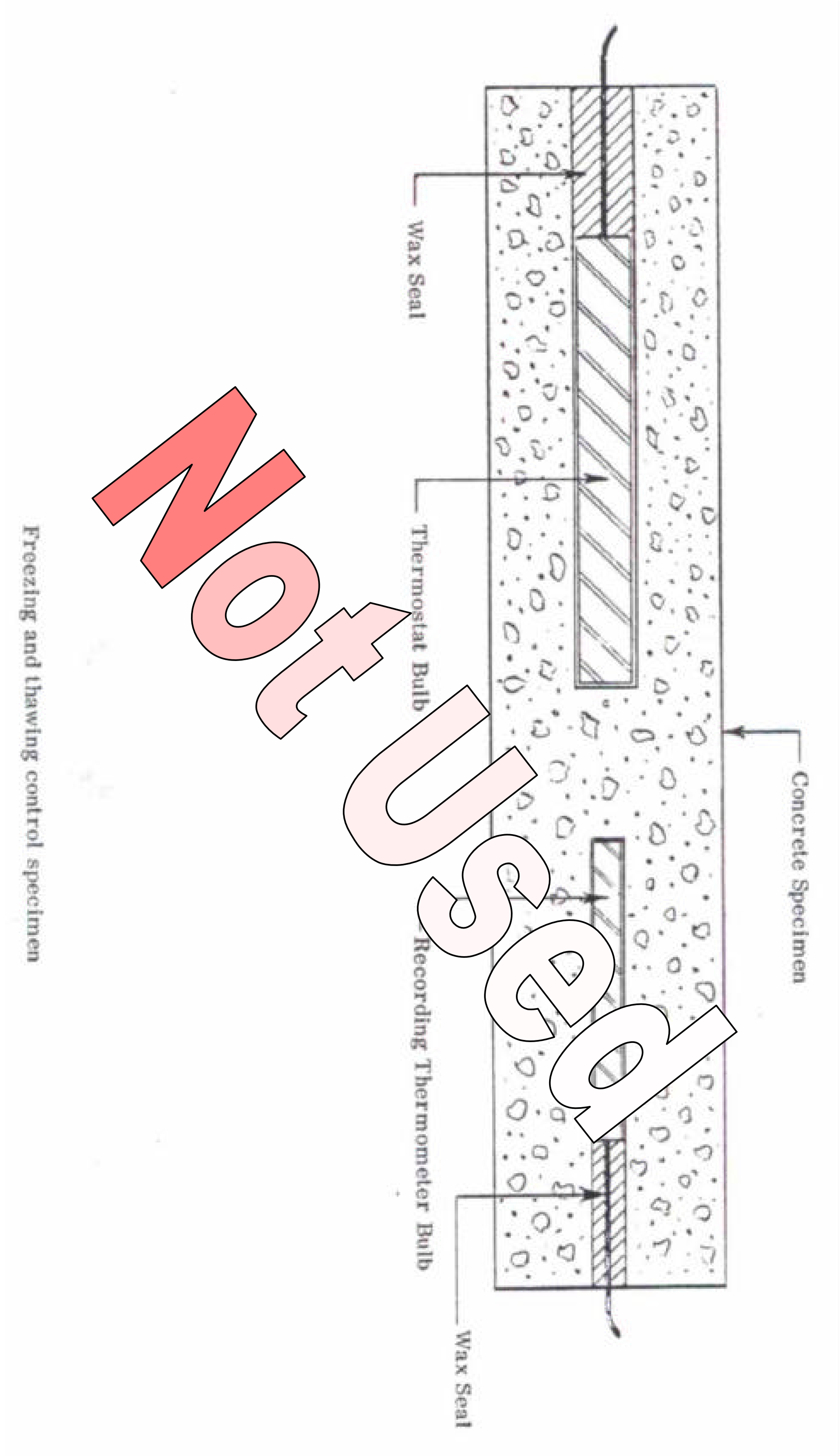

Figure H3 – Original Temperature Control Specimen (not used)

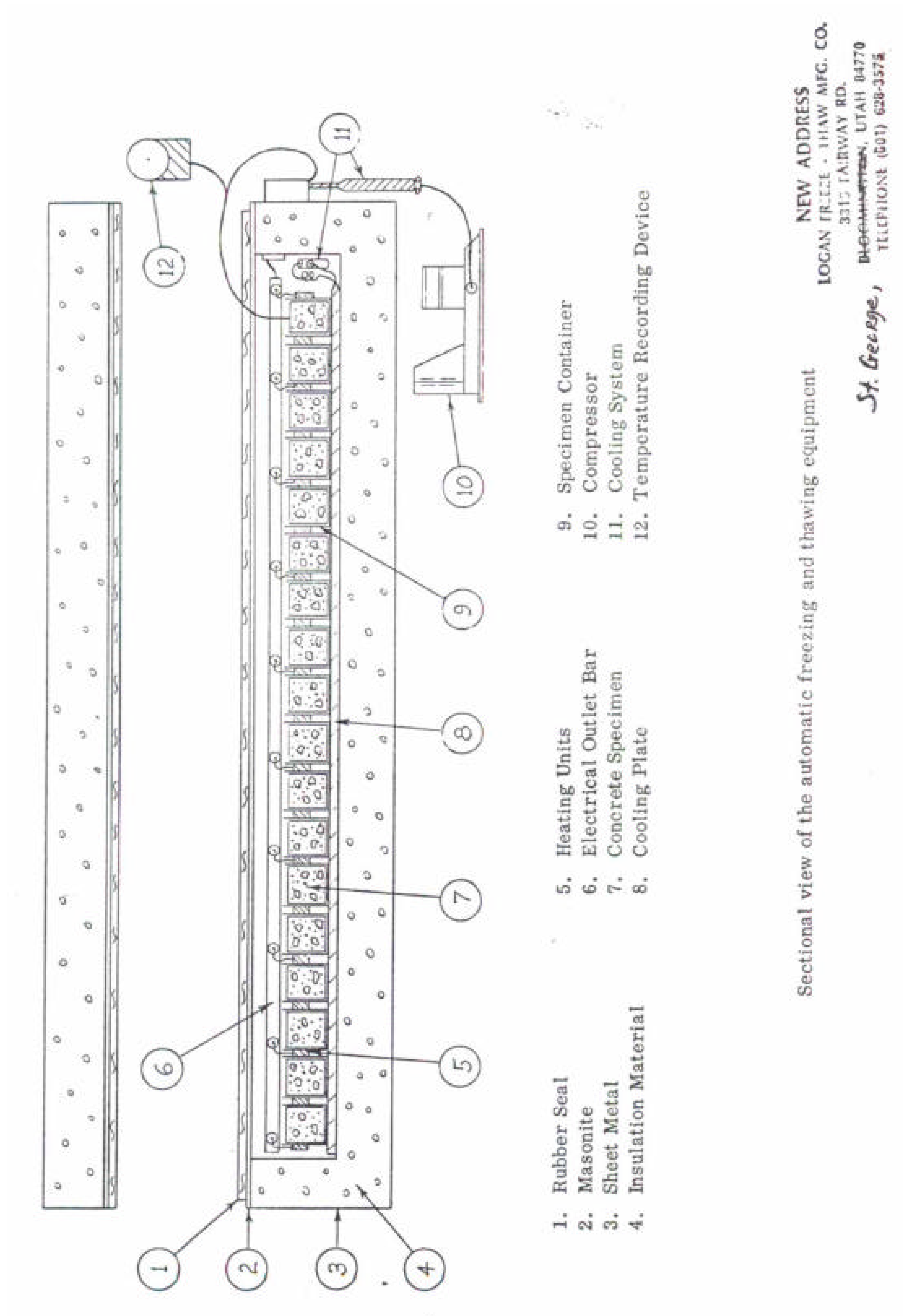

Figure H4 – Sectional View of the Automatic Freezing and Thawing Equipment

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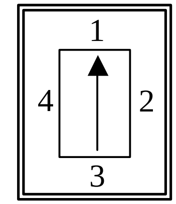
Specimen Placement Randomization Chart

SPECIMEN ORIENTATION



ARROW AS MARKED ON SPECIMENS

Numbering of Specimen Compartments

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18

FAN →

Specimen #	T_1	T_2																DATE	CYCLE NO.	SIDE FACING UP
Cycle Replaced w/Dummy																				
	4	15	14	5	12	2	16	9	6	17	13	11	3	10	18	7	1	8	- -		1
	4	15	16	7	10	9	13	17	14	8	12	1	11	3	5	18	6	2	- -		3
	4	15	13	9	18	2	6	1	3	17	8	5	7	11	12	10	16	14	- -		1
	4	15	6	13	16	2	18	12	1	14	11	7	3	5	9	10	8	17	- -		3
	4	15	5	3	10	17	11	9	6	13	2	14	12	18	1	16	7	8	- -		1
	4	15	12	2	8	1	10	3	7	9	5	14	18	11	13	17	16	6	- -		3
	4	15	11	17	12	14	13	18	8	3	16	2	10	9	6	7	5	1	- -		1
	4	15	16	17	14	18	11	12	1	13	3	10	7	8	9	2	6	5	- -		3
	4	15	17	12	10	13	9	6	3	11	5	7	14	16	18	2	8	1	- -		1
	4	15	5	1	7	16	9	11	8	3	10	14	2	17	12	13	6	18	- -		3
	4	15	18	2	14	1	13	9	3	7	17	12	6	8	11	5	16	10	- -		1
	4	15	11	3	12	5	17	13	16	1	9	8	14	18	10	7	6	2	- -		3
	4	15	14	10	1	12	16	8	18	13	2	3	17	11	7	9	5	6	- -		1
	4	15	9	16	3	10	14	7	12	6	18	13	2	11	1	17	8	5	- -		3
	4	15	10	18	11	12	1	6	7	8	9	5	3	14	13	16	17	2	- -		1